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PRACTICAL ASTRONOMY



FRONTISPIECE. Celestial Globe of Dutch manufacture (1603). These instruments enabled astronomers and navigators to solve astronomical problems without having to resort to mathematical formulae and tables.

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PRACTICAL ASTRONOMY

*A New Approach
to an Old Science*

W. SCHROEDER

Member of the British Astronomical Association

Werner Laurie

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The fascination of the starry realm is there for all to see
whose eyes are not closed to the wonders of the universe,
and who can still feel awe in the face of Eternity.

ASTRONOMY is something more than a mapping of the firmament and the recording of stellar and planetary movements. Everyone who takes an interest in the stars feels, far back in his mind, the same mystery that took hold of the astronomers of ancient Babylon and Egypt, to whom the immensity of the universe was a divine revelation.

Do not we feel the same, still, when we raise our eyes to the stars on a bright and clear winter's night? Does it not make us wish we knew a little more about the star-spangled heavens, which make our own little world recede into insignificance?

He who never raised his eyes, be it in mere admiration, or in search for knowledge, to the depths of star-studded space, lacks an important link in the chain which connects him with the world around him. For the use of astronomy is not merely that it enables us to put our clocks right or sail our ships across the oceans, but that it broadens our mental horizon, and thus provides us with the fundamentals of a more comprehensive conception of life and of the world in which we live.

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*The maps and diagrams
have been drawn by Charles Green
from material supplied by the author.*

Foreword

ASTRONOMY is a peculiar science. It puts the writer of elementary books on the subject on the horns of a dilemma, for he either tells of the evolution of stars, their spectral types, the structure of the Universe and the surface details of the planets, or else he tells of the more obvious happenings in the sky, such as the movements of the planets, the phases and the path of the moon, and all those phenomena associated with the Earth's daily rotation.

In the first case, his readers just have to accept the author's word, for the verification of any of his statements requires telescopes of a size which the reader is unlikely to ever have the opportunity to use. In the second case he leaves his readers with a sense of dissatisfaction, because he cannot make his explanations convincing without assuming at least some mathematical knowledge on the part of the reader.

I have tried here to approach this latter problem from a new angle. Everyone has, at one time or another, unknowingly applied principles of, say, Integral Calculus, when making a sketch or diagram. Calculus may be one of science's mysteries to him, but the sketch is there, easy to understand. So it is in this book. Mathematical formulae are there, but disguised as simple graphs and diagrams. With no more mathematical ability than that of adding together half a dozen figures, the reader is enabled to calculate the times of eclipses, and to find a ship's position at sea, provided he can handle a pencil, ruler and compasses. The accuracy of these methods is surprising, and equals that obtained by navigators and astronomers of not so very long ago.

The problems involved, as well as those which it is often necessary to solve as a preliminary to the observation of stars or planets, can be dealt with by making one or two diagrams, an occupation which is

admirably suited to a wet, winter's evening, and if they are regarded as conundrums, just to pass the time away, they serve their purpose just as well, being, however, more useful than a successful attempt at the weekly crossword puzzle.

Used in this manner, this book will probably become a reference work for the reader rather than an introduction to astronomy. As such it will be taken from its shelf perhaps as many as seven times a week, if only for a short while. And if, after perhaps as long a time as a whole year, the reader has been induced to work out a few problems for himself, or to make some observations, then I shall be satisfied that it has well served the purpose for which it was written.

Ferriot's Farm
Belchamp St. Paul's
Sudbury, Suffolk
October, 1955

W. SCHROEDER

I

Our World

WHAT IS it really like, this world of ours? This question, simple as it seems, is not easy to answer. Looking at the star-spangled heavens, it seems as if the Earth were a flat disc, with a large dome overhead to which the stars are fixed. In this way, the Universe has been pictured for thousands of years, and only very few, progressive minds ever expressed doubts that this was a true representation.

Civilizations grew and perished, empires were built and fell in ruin again, but the concept of the world remained unchanged.

During the third century B.C., Aristarchus of Samos came to the conclusion that the Sun, and not the Earth, is the centre around which the planets, and with them our Earth, revolve. His ideas, however, were not accepted and his teachings became forgotten.

After that, it took mankind nearly two thousand years to let itself be convinced by the fact that our Earth is not at the hub of the Universe, and that it is not a fixed body, around which everything else revolves.

Nicolaus Copernicus first pointed out the true nature of the Solar System. The planets, among them our Earth, circle around the sun, the centre of the system, and all the other, fixed, stars are at an immense distance and provide the background for the ballet of the planets. Their strange paths among the stars thus find a simple explanation. What we actually observe are the combined movements of the planet and the Earth, and this results in the curious loops and curves which the planets apparently describe, and which have puzzled the astronomers of ancient Greece and Babylon.

When the great Danish astronomer, Tycho Brahe, died in 1601, he left his notes on his observations, especially those of the planet Mars, to Johannes Kepler. Tycho's observations were at least ten times as accurate as any others made previously, and with such material

to work on, Kepler discovered the laws of planetary motion, which are named after him. These laws confirmed the teachings of Copernicus, but Kepler found the planetary orbits to be ellipses, and not circles as Copernicus thought. Also, the speed with which the planets move along their orbits was found to vary. They move faster when they are near the Sun, and more slowly when they are farther away from it.

Johannes Kepler's writings on his discoveries prepared the path for Newton's Law of Gravitation. While Kepler had discovered the *how* of planetary movements, it was left to the mathematical genius of Sir Isaac Newton to explain the *why*.

The invention of the telescope provided astronomers with other surprises. The Milky Way, that faint, luminous band across the sky, was found to consist of millions and millions of stars, and small, bright patches in the sky were found to be other systems of stars, like that of our Milky Way in which the Sun is merely one among an immense number of other stars.

The bigger the telescopes became, the more stars and nebulae were discovered, and the Universe was found to be thousands of times larger than it was thought to be in even the wildest imaginations of the ancients.

And this is what the picture looks like. Our cosmic home is the Earth, which, with her sister planets Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto, revolves around the Sun. If the Sun were diminished to the size of a pinhead, the Earth would be no larger than a dust particle, circling around it at a distance of about three inches. Eight other dust particles at various distances represent the remaining planets, and the whole system could comfortably be accommodated in an average-sized room.

The Universe, it might be thought, is rather empty. But these dust particles are comparatively close together, for we should have to travel at least twenty-five miles before we came to the next pinhead, representing the star Proxima Centauri, our nearest neighbour in space.

It is obviously a futile attempt to measure the distances of stars in miles, and so astronomers have chosen a different unit of length. The light, like radio waves, travels about 186,000 miles, that is seven and a half times along the Earth's equator, every second. In the course of a year, it covers the immense distance of six million million miles, and this is what astronomers call a light-year, the astronomical unit of distance. Our nearest neighbour is four such units away, and the largest telescopes enable us to photograph spiral nebulae which are millions of light-years away from us.

Our Sun is only a star like many others, and rather a small one it is, too. Like all the stars which are visible to the naked eye, it belongs to the Milky Way system, which is a collection of many millions of stars, arranged in the shape of a lentil, and to an outside observer this would appear just like the spiral nebulae appear to us. The diameter of this 'lentil' is about 100,000 light-years, and its thickness 20,000 L.Y.

Far beyond the boundaries of our Galaxy, our large telescopes show us millions of spiral nebulae, other Milky Way systems. The nearest of these is the Great Nebula in Andromeda, according to the latest measurements at a distance of one and a half million L.Y., and its shape and size are almost the same as those of the Milky Way.

The largest telescope on Earth penetrates the Universe to a distance of 2,000 million L.Y., and physicists tell us that the size of the Universe is 3,200 million L.Y. Whatever apparatus we may use in future, the physical properties of light and matter will bar us from penetrating beyond that limit. But up to that distance we shall probably find many more Galaxies, once telescopes become larger still, but that which lies beyond will be hidden from our knowledge for ever.

2

From the Stargazer's A B C

DAY AND NIGHT

THE APPARENTLY flat Earth with its dome of stars overhead is a mere illusion. The Earth is nothing but a small, round body, and the sky is not a dome but a sphere which surrounds us on all sides. In twenty-four hours, the Earth rotates once round her axis, and each part of her surface is turned towards the Sun during part of that time, and for the remainder it is turned away from him, thus alternately causing day and night.

This rotation of the Earth also causes the stars to rise and set, just as the Sun does, but to us it appears as if it is the star sphere which revolves around us.

The Earth is very nearly a sphere, but its rapid spinning around has flattened it out a little. Its diameter, measured across the equator, is about 7,927 miles, while the distance from pole to pole is only 7,900 miles.

POLES AND EQUATOR

The imaginary line through the Earth from one pole to the other is called the Earth's *Axis*, and if this were extended into the sky, it represents the axis around which the star sphere apparently rotates. Like the Earth, the celestial or star sphere has a North and a South Pole. These are the points where the extended axis of the Earth cuts through the celestial sphere.

It must not be forgotten, however, that the stars are actually at greatly varying distances from us, and to regard them as fixed to a sphere is merely a convenient way of representing the sky. For all practical purposes, this causes no difficulties, as all the distances on

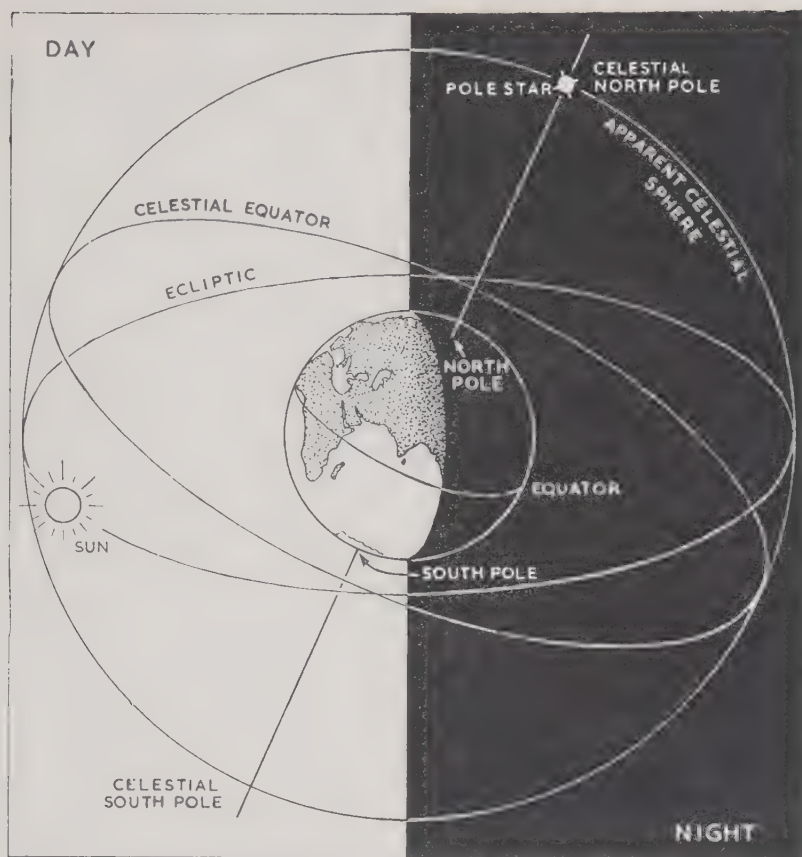


Fig. 1. The Earth and the celestial sphere

Earth, or for that matter in our Solar System, are infinitely small compared with stellar distances.

For us, on the northern hemisphere, the celestial North Pole is conveniently marked by a fairly bright star. Because of its position, it is called the *Pole Star*, or *Polaris*, and this is the only star which seems to be fixed in the sky, all the others apparently circling around it, each at its particular distance from the pole.

The equator divides the Earth into a northern and a southern hemisphere, and the plane of the equator is at right angles to the axis. If the plane of the Earth's equator were extended until it meets the celestial sphere, the line of intersection thus obtained is the celestial equator.

THE EARTH'S TIME-TABLE

Like the other planets, the Earth travels around the Sun, completing her orbit once every $365\frac{1}{4}$ days. The only evidence of this yearly travel is the apparent motion of the Sun, as seen against the background of the stars.

The length of our days from one midnight to the next is determined by the time the Earth takes to make one rotation with respect to the Sun. But, as the Sun travels a little way along his yearly path during that one day, the Earth has to make a little more than one whole rotation with respect to the stars in order to get into the same relative position to the Sun, and thus the stars reach a given position in the sky four minutes earlier every night, and the aspect of the night sky changes with the seasons.

The path along which the Sun travels in the course of a year is called the *ecliptic*, and this is inclined to the plane of the equator at an angle of $23\frac{1}{2}$ degrees; this inclination is due to the fact that the Earth's axis is not perpendicular to the plane of her orbit, but departs from the perpendicular by $23\frac{1}{2}$ degrees.

The imaginary band, 8 degrees wide, on each side of the ecliptic, is the Zodiac (Circle of the Animals). The Sun, the Moon, and the planets are always within this band, which is divided into twelve equal parts, each of which is 30 degrees long. These parts are called the Signs of the Zodiac and they bear the names of twelve constellations. But the signs no longer coincide with the constellations after which they were named, as a slow movement of the Earth's axis, the *precession*, makes the celestial poles and the equator move before the background of the stars. Thus, the position of the starting point of the signs also moves, as they are counted from the point where ecliptic and equator intersect each other, and this point, owing to the precession, travels around the ecliptic once every 26,000 years.

A few thousand years ago, however, the Zodiacal Signs did coincide with the constellations whose names they were given, but now it so happens that the Sun, when in the sign of Aries, is actually in the constellation Pisces.

THE SEASONS

During her yearly journey, the Earth always keeps her axis pointed towards the Pole Star, and therefore the Earth's North Pole is tilted towards the Sun at one part of her orbit, and away from it at another.

ARIES The Ram		TAURUS The Bull		GEMINI The Twins	
CANCER The Crab		LEO The Lion		VIRGO The Virgin	
LIBRA The SCALES		SCORPIUS The Scorpion		SAGITTARIUS The Archer	
CAPRICORNUS The Goat		AQUARIUS The Water-Bearer		PISCES The Fishes	

Fig. 2. Signs of the Zodiac

While it is tilted towards the Sun, it is summer on the northern hemisphere, and when it tilts away from him, it is winter.

In our latitude, the Sun is almost overhead at noon in the summer, and we receive the maximum of the Sun's heat-rays. In the winter, when the Sun is low in the sky, his rays reach the surface of the Earth at our latitude slantwise, even at noon, and the same amount of heat which, in the summer, warms one square foot of ground, is now spread over more than two square feet, with the result that it is much colder in the winter than it is during the summer.

THE STARS

On a clear winter's night, when the stars are twinkling in the cold air, there seem to be millions of them, yet it is surprising how few we can really see. In the whole heavens there are no more than 6,000 stars which, theoretically, are visible to the naked eye. At any one time, about half of these are below the horizon, and of the remainder, about one-third are visible only to someone with extremely keen eyesight and at a time when observing conditions are really exceptional. We thus arrive at the surprisingly small number of 1,500 or 2,000 stars which can be seen under normal conditions.

The famous Greek astronomer, Hipparchus, divided these into six magnitude classes. The twenty brightest stars in the sky are said to be of first magnitude, stars of the second are somewhat fainter, and the faintest stars visible to the naked eye are of magnitude six.

This scale is arranged in a manner which makes a star of the first magnitude exactly 100 times as bright as one of the sixth magnitude,

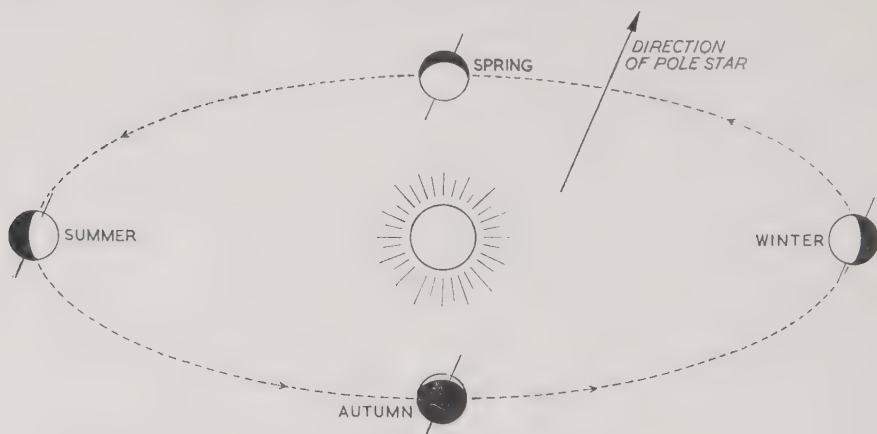


Fig. 3. The Earth in her orbit

and the ratio of brightness between one class and the next higher one is $1:2.512$.

This ratio, once fixed, makes it possible to classify stars which can be seen in telescopes only. A good pair of binoculars will show stars down to the 9th or 10th magnitude, and the 200-inch telescope on Mount Palomar, which is the biggest on Earth, is capable of recording, on photographic plates, stars of the 23rd magnitude. The difference between such a star and one of the first magnitude is the same as that between two candles, one at a distance of one yard, and the other nearly forty miles away.

THE NAMES OF THE STARS

Most of the brighter stars have been given names by the astronomers of Babylon and Greece or by the Arabs during the Middle Ages. We still retain many of these: Castor, Pollux, Procyon, Altair, and Antares are names of Greek origin. The Arabs named many other stars like Betelgeuze, Rigel, Aldebaran, and Deneb, and especially the names of

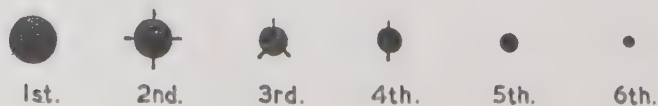


Fig. 4. Star magnitudes

α	Alpha	ι	Iota	ρ	Rho
β	Beta	κ	Kappa	σ	Sigma
γ	Gamma	λ	Lambda	τ	Tau
δ	Delta	μ	Mu	υ	Upsilon
ϵ	Epsilon	ν	Nu	ϕ	Phi
ζ	Zeta	ξ	Xi	χ	Chi
η	Eta	$\omicron$	Omicron	ψ	Psi
θ	Theta	π	Pi	ω	Omega

Fig. 5. The Greek alphabet

the fainter stars are of Arabic origin: Zuben el Genubi, Benetnasch, Algenib, Mirfak, and Ras Alhague.

As it would have been impossible to find names for all the stars, Johannes Bayer, a German astronomer (1572-1625) devised a system which made it possible to designate the majority of stars.

To the brightest star in any constellation, he assigned the first letter of the Greek alphabet, to the second brightest the second letter, and so on. There are a few departures from this rule, made for convenience, as, for instance, in Ursa Major (the Great Bear), but in general this is the system employed. Thus, Betelgeuze, the brightest star in the constellation Orion, is called α (*alpha*) Orionis, the second brightest, Rigel, is called β (*beta*) Orionis, Vega, the brightest star in the Lyre is called α (*alpha*) Lyrae, and so on. The Latin name of the constellation, in its genitive form, always follows the Greek letter.

When the letters of the Greek alphabet are all used, numbers designate the fainter stars, according to the system introduced by Flamsteed, the first Astronomer Royal. There are a few other methods of star designation, which are convenient for one reason or another, but these are normally explained in the Star Atlas or Catalogue in which they are employed.

The Sun		Minor Planets	
The Moon		Jupiter	
Mercury		Saturn	
Venus		Uranus	
Earth		Neptune	
Mars		Pluto	

Fig. 6. Astronomical symbols

THE CONSTELLATIONS

The names given to the different constellations by the astronomers of the ancients are still in use today. Many of these, like the ones of individual stars, are those of characters from Greek mythology, but the origin of the names of the constellations in the Zodiac is lost in antiquity.

During the last century, proper constellation boundaries were introduced for the first time, making it possible to assign even the faintest and apparently unconnected stars to a definite constellation.

Some of the constellation names are comparatively recent additions, which were introduced in order to group together a number of faint stars which did not quite fit into the pattern of the ancient configurations.

As the southern skies were unknown to the Greek astronomers, the constellations in that part of the heavens are all modern additions. They have been given such prosaic names as Furnace, Pendulum Clock, Table Mountain and Telescope.

Nowadays, the ancient names have little significance, but they are convenient for the naming of stars, and make it easier to identify them.

MEASURING ANGLES

The apparent distances between stars or between other points on the celestial sphere are always given in angular measurement, that is, in degrees. Thus, the distance from the *zenith*, that point in the sky which is directly overhead, to any point on the horizon, is ninety degrees, usually written 90° .

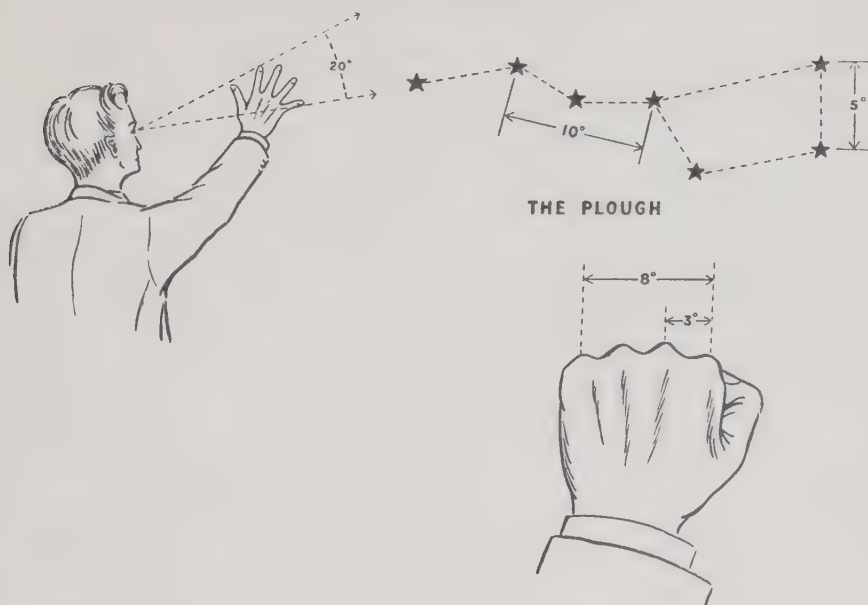


Fig. 7. Measuring angles

For the purpose of estimating angles, it is useful to remember a few measurements of particular distances. For rough estimations the angle subtended by one's fist, held at arm's length, is about 8° , while the tip of the first finger at the same distance covers an angle of about 1° . The stars α and β of the Great Bear (Ursa Major), usually called the Pointers because they indicate the direction of the Pole Star, are about 5° apart, and the diameter of the Full Moon is $\frac{1}{2}^\circ$.

Close to the star ζ (*zeta*) Ursae Majoris (Mizar) there is a faint star which the naked eye is only just able to see. This little star is called Alcor—the Rider—and the two are about one-fifth of a degree apart. Their exact distance from each other is 11 minutes of arc, one minute being one-sixtieth of a degree. In order to make a distinction between these and minutes of time, they are always called minutes of arc if there is any possibility of confusing the two.

For greatest accuracy, these minutes of arc are again subdivided, each into sixty seconds of arc. The abbreviated manner of writing,

for instance, six degrees, twenty-four minutes and eighteen seconds of arc is :

$$6^{\circ} \quad 24' \quad 18''$$

Minutes and seconds of arc are very small angles, one minute being the angle subtended by a halfpenny at a distance of 100 yards, and a second is the angle subtended by a halfpenny at a distance of $3\frac{1}{2}$ miles.

For the purpose of measuring angles, which may be necessary when making a map of a constellation, it is very convenient to have a ruler handy, into which notches have been cut at each division of one centimetre. Held at arm's length, the distance between two notches is approximately one degree.

3

Stars Which are Visible Throughout the Year

THE DAILY rotation of the celestial sphere around its axis makes the stars, like the Sun, rise in the East, attain their highest position in the sky in the South, and finally set in the West.

As the stars in their daily path apparently circle around the Pole Star, it seems that there must be some which never rise nor set, but are always above the horizon. If we look towards the North, we shall find the constellation of the Great Bear, or, at least, that part of it which is often called the Plough. Perhaps it is low, near the horizon, maybe right overhead. But whatever its position, the imaginary line through the two Pointers and extended about five times, brings us to the Pole Star.

A line, from the Pole Star to the horizon directly below, cuts this in the North Point, and all stars which are not farther away from the Pole Star than is the North Point, can never disappear below the horizon: they are visible at all times of the year, and are called *circumpolar stars*.

All the stars of the Great Bear have been given names, and the sequence of the Greek letters used to designate them is not in the order of decreasing brightness, but follows the sequence of the stars in the constellation. The star α (*alpha*) is called Dubhe, β (*beta*) Merak, γ (*gamma*) Phecda, δ (*delta*) Megrez, ϵ (*epsilon*), the brightest star of the constellation, is called Alioth, ζ (*zeta*) Mizar, and η (*eta*) is called Benetnasch.

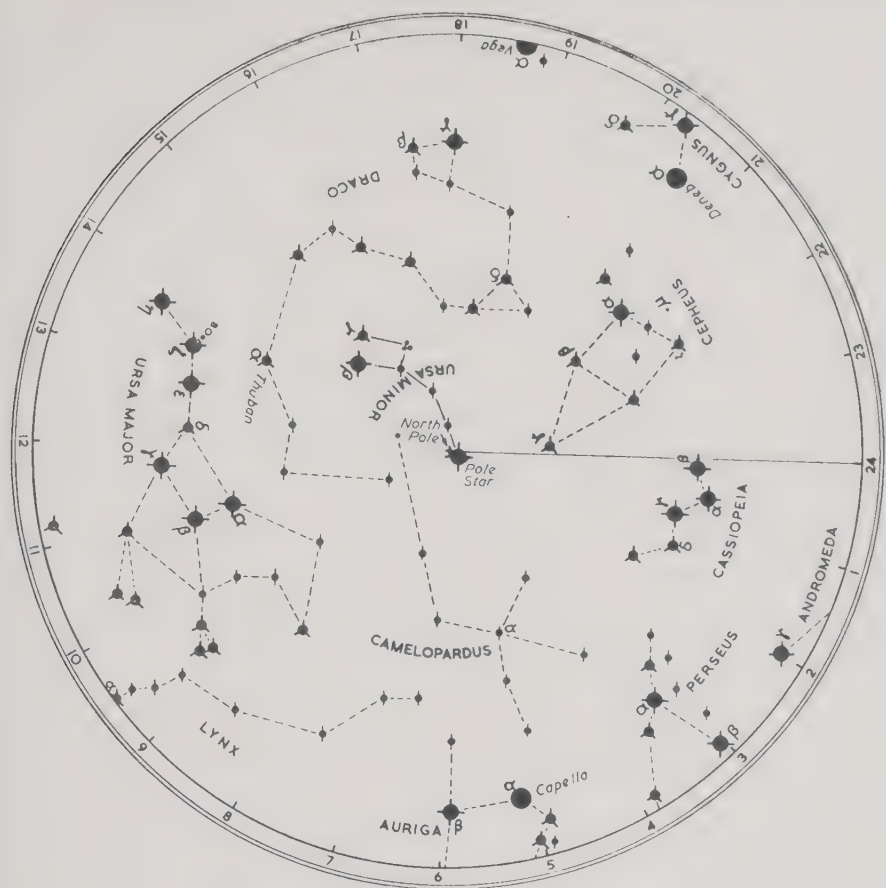
Near Mizar is the little, 5th magnitude star Alcor (80). It is plainly visible to the naked eye on a clear night, but either its brightness or the distance from Mizar must have increased during the past few centuries, as it used to be considered very difficult to see this star, and only the keenest eyesight was thought to be able to recognize it.



Fig. 8. Different positions of Great Bear

The Pole Star belongs to the constellation Ursa Minor (the Little Bear), which has a shape similar to that of Ursa Major, but its stars are much fainter. Polaris is the brightest of the constellation, and has the letter α (*alpha*) assigned to it. β (*beta*) and γ (*gamma*) are called the Guardians of the Pole, and β (*beta*) also has the name Kochab, which means Star of the North.

About two thousand years ago, when it was given this name, it actually was the Pole Star, but the celestial North Pole has wandered off in the meantime. This strange movement of the Pole among the stars is caused by the precession, a wobbling movement of the rotating Earth, which also causes the shifting of the Zodiacal Signs. Just like a child's spinning top, the Earth's axis does not remain completely steady, but describes a small circle, with the result that the celestial Pole moves along among the stars, describing a circle of $23\frac{1}{2}^\circ$ radius once every 26,000 years.



Map 8. The Circumpolar Constellations

Between the two Bears, there is a number of rather faint stars which make up the constellation Draco (The Dragon). Its tail is between the Pointers and the Pole Star, and its string of stars almost circles the Little Bear. Half-way around, however, it turns back on itself, and finally reaches two somewhat brighter stars, representing the Dragon's Head. Half-way between Kochab and Mizar is the star α (*alpha*), also known as Thuban. 4,500 years ago it was the Pole Star, and the Egyptian Pyramids were built with this star determining their geometrical properties.

If we draw a line from the Pointers to the Pole Star and beyond, we

come to the star γ (*gamma*) in the constellation Cepheus. This consists of five stars somewhat in the shape of a house, seen from its gable end. Just below the base line, half-way between α (*alpha*) and ζ (*zeta*), is the 5th magnitude star μ (*mu*). On clear nights, this star is remarkable on account of its deep red colour, which is even more striking when it is seen through binoculars. Sir William Herschel very aptly named it the Garnet Star.

Opposite the Great Bear, on the other side of the Pole, we find the beautiful constellation Cassiopeia. Its W-shape makes it one of the most conspicuous constellations in the sky, especially as all its stars are comparatively bright and close together.

If we draw a line through the two uppermost stars in the body of the Great Bear (ζ and α), and project it about three times, it will indicate the positions of two faint stars which belong to the small and inconspicuous constellation Lynx.

Between this and Cassiopeia is a number of faint stars which are grouped together under the name of Camelopardus (the Giraffe). Only seven of the 150 visible stars are brighter than magnitude 5. The head of the giraffe must be imagined between the Dragon's tail and the Pole Star, and its legs are near the second brightest star in the northern heavens, Capella, which belongs to Auriga (the Charioteer).

The brightest star north of the celestial equator is Vega in Lyra (the Lyre), and this is almost opposite Capella, but at a slightly greater distance from the Pole. These two stars move up and down in see-saw fashion. When one of them is low, almost on the horizon, the other will be found high up in the sky, their positions changing continually with the time of the night and with the seasons.

4

The Clock in the Sky

THE CELESTIAL SPHERE with the stars makes one complete revolution in 23 hours and 56 minutes. This apparent movement, caused by the rotation of the Earth, is so regular that astronomers use the stars exclusively to determine the correct time with the greatest possible accuracy.

Let us imagine a huge dial, fixed in the sky, with its centre at the celestial North Pole. The Pointers of the Great Bear may then represent the hour-hand of this clock, but how are we to read the time from it? It is not a simple matter. The hand, for one thing, moves anti-clockwise, and for another, it does not, like on an ordinary clock, turn round once in twelve hours, but takes 24 hours to do so. On top of it all, it gains four minutes every day, or about two hours a month.

Yet it is possible to find the time from the position of the Pointers without the instruments which astronomers have at their disposal, if we remember that, at midnight on 7 March, this clock in the sky indicates 12 o'clock.

As the hand turns anti-clockwise, it will indicate 11 o'clock two hours later, and 10 o'clock four hours later. We should, therefore, read the time from an imaginary 24-hour dial, but we can regard it as an ordinary one, showing divisions for 12 hours only, and simply double the time thus indicated. Taking into account the anti-clockwise movement of the hour hand, we subtract our result from 24. If, on 7 March our 'clock' shows '10', we simply double this, which gives us 20, and, subtracting this from 24, we obtain the result 4. This is 4 o'clock in the morning, because 4 P.M. would have left us with the result 16. For every month after March we have to subtract two hours from our result in order to obtain the correct time.

For ease of calculation, this formula can be expressed simpler still:

read off the time shown by the Pointers, if possible to the nearest quarter of an hour, add the number of months passed since 7 March, also correct to the nearest quarter, and multiply the result by 2. The figure thus obtained is then subtracted from 24, or, if it is greater than this, from 48, and this last result is the time at the moment. With some practice it is quite possible to determine this with an accuracy of about a quarter of an hour.

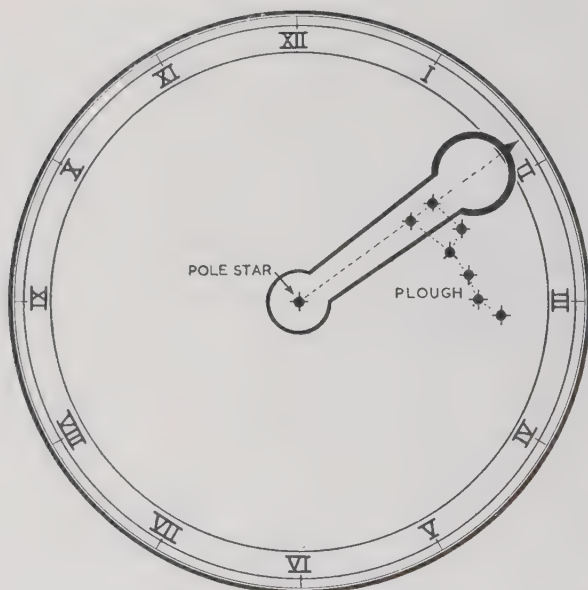


Fig. 9a. The clock in the sky

THE NOCTURNAL

A few hundred years ago, when calculations of this kind often were beyond people who were considered to be quite well educated otherwise, the Nocturnal was used for the purpose of finding the time by night. This performed the calculations automatically, and consisted of a round disc with two scales, one from 0 to 24 hours, and the other from 1 January to 31 December. A mark on the handle was set against the date by turning the disc about its centre, and the instrument was then held against the sky, so that the Pole Star became visible in the little hole in the centre, while the handle was held in such a position



PLATE I. Trails of the Circumpolar Stars, made during an interval of three hours. The brightest trail, near the centre, is that of the Pole Star. All these trails diminish in brightness towards their ends, owing to a gradual development of haze or cloud.

Royal Observatory, Greenwich

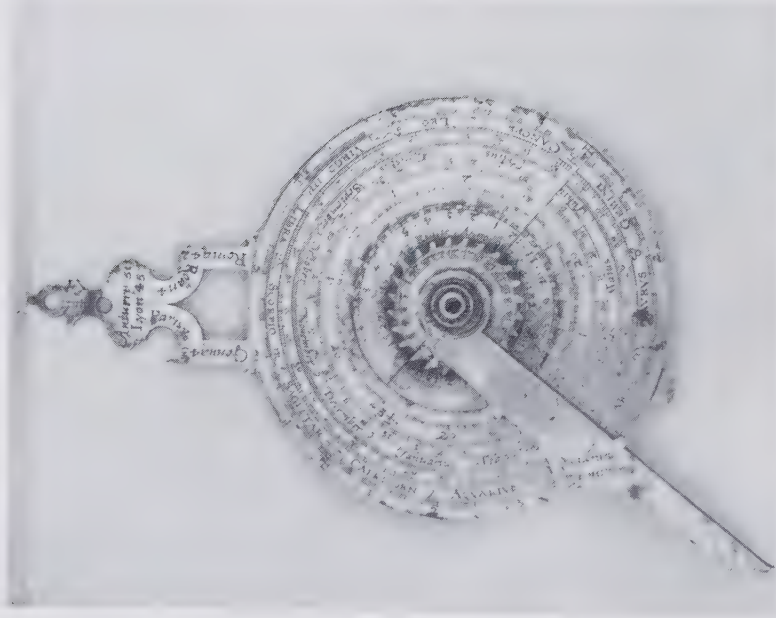


PLATE II. Dutch Nocturnal of the Sixteenth century. With the aid of this instrument the time of night can be found from the position of the constellation of the Little Bear.

By courtesy of the Curator of the Museum of the History of Science, Oxford

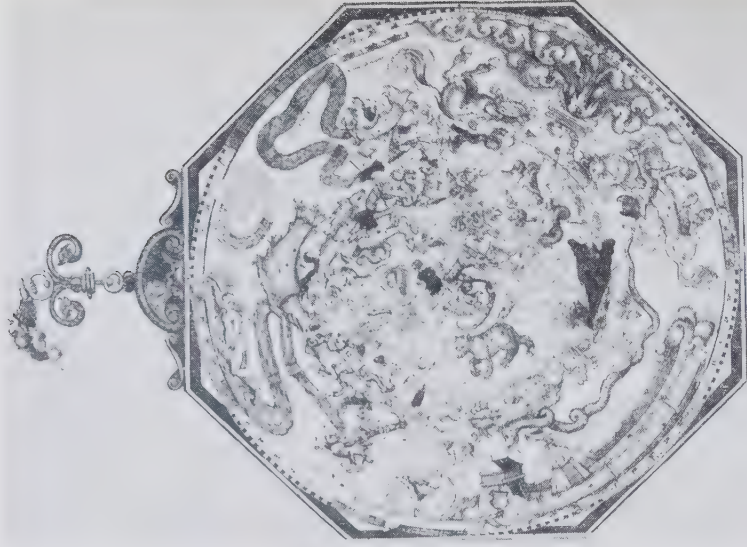


PLATE III. Mediacal Star Map from Peter Apianus' work *Astronomicum Caesareum*, published in 1540.

From a photograph in the Science Museum, South Kensington. Reproduced by permission of the Royal Astronomical Society

that it pointed directly at the North Point of the horizon, that is accurately perpendicular. Then the hour-hand of the instrument was rotated until it coincided with the Pointers of the Great Bear, or some other star, depending on the construction of the instrument, and the hour-hand then indicated the time on the 24-hour scale.

Such a star clock, or to call it by its correct name, Nocturnal, is quite simple to construct. A circular cardboard disc of about six inches diameter carries along its edge a scale of dates, starting from 1 January, and continuing to 31 December. Inside this is another circular scale, from 0 to 24 hours, arranged so that '24 hours' is exactly opposite the date of 7 March. This hour-scale progresses in an anti-clockwise direction, while the dates progress clockwise. In the exact centre of this disc, a hole is then punched, just large enough to take a small, hollow rivet.

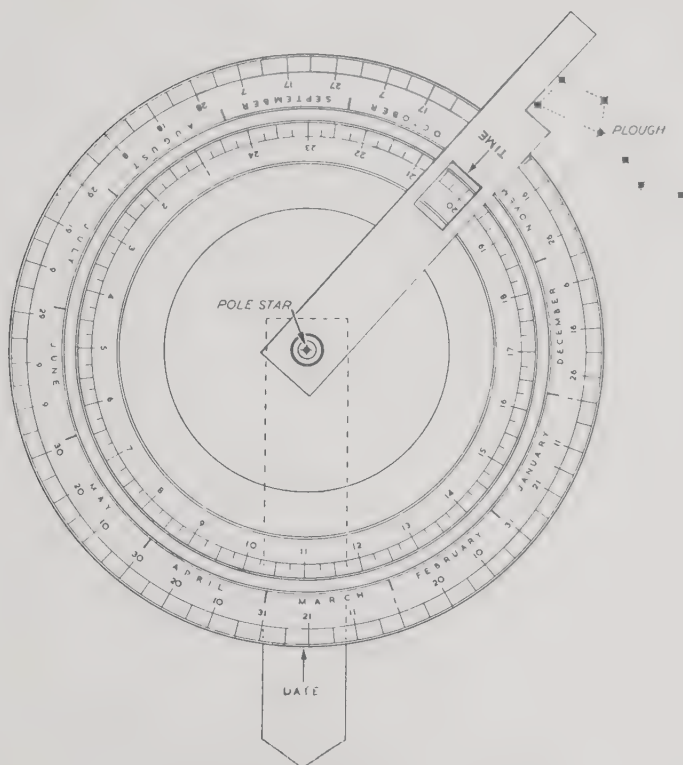


Fig. 9b. Nocturnal made from cardboard

A handle of rather stronger cardboard has a similar hole on its centre line, but towards one of its ends, as well as an arrow which is to point against the dates on the disc. The rivet is then passed through the handle from underneath, the disc is placed on top of this, and finally the hour-hand. Then, the rivet is hammered open to keep the three parts together, but it should be possible to rotate the three parts without having to force them.

The accuracy of the instrument depends on its size, and the exactness with which the handle is held perpendicular. But even a small instrument is capable of indicating the time correct within about ten minutes or so. This Nocturnal cannot, of course, replace a watch or clock, but it very well illustrates that, after all, it is the rotation of the celestial sphere from which we determine our time.

The principle of the instrument is obvious. From the starting date, midnight on 7 March, the Pointers gain four minutes every day, and by adjusting the disc for the date, we have to turn it a little every day, just sufficient to make up for these four minutes, as, in this way, the hour-hand has to make a little more than a whole revolution to reach the same hour of night again after the interval of 24 hours. This is exactly as it should be, as the stars, too, make just that little bit more than one revolution in 24 hours.

5

More Constellations

ONCE WE remember and recognize the circumpolar constellations, it is easy to find our way about the heavens, as the Stars of the North provide us with the signposts which lead us on to the other constellations. On a clear night, preferably when there is no moon, the map on page 29 should be compared with the sky until the constellations are recognized. It will be a bit difficult at first, but once the Great Bear is found, and the map turned round until it coincides with the position of that constellation, the others will soon be found.

Except for the circumpolar ones, all constellations are below the horizon at one time or another. For this reason, many of the 'sight-lines' indicated in the following pages, will lead us on to the horizon. To avoid any unnecessary searching, dates are given with each constellation, which indicate the time of the year during which it is above the horizon in the evening, as soon as darkness has fallen.

THE HERDSMAN

If we follow the curved line indicated by the last three stars in the tail of the Great Bear, we shall come to a brilliant, golden star. This is Arcturus, and it belongs to the constellation Bootes (Apr.-Oct.)

There are a few faint stars on either side of Arcturus, but the main part of the constellation stretches towards the North Pole, somewhat in the shape of a kite. The star ϵ (*epsilon*) is a double star: a telescope shows that there are actually two stars where the naked eye can see only one. The two components of this particular star show a striking colour contrast, the brighter one is orange, and the fainter is of a pale, bluish green. So remarkable is this contrast that the star was named Pulcherrima—The Most Beautiful One.



Map 1. Ursa Major, Bootes, Virgo and Corvus

THE VIRGIN

If we follow the curve from the Great Bear over Arcturus farther South, we come to Spica, the brightest star in Virgo (Apr.-July), which stretches over a considerable part of the sky and is one of the Zodiacal constellations. ϵ (*epsilon*) Virginis has the beautiful name Vindemiatrix, meaning Mistress of the Vineyards. It has been called thus by the ancients because it becomes visible in the morning sky again after being hidden by the sun while he was in that constellation, at that time of the year when the grapes are ready to be harvested.

The meaning of the name Spica is Ear of Corn, with which the Virgin was always pictured on the ancient star-maps. (See Plate III.)

THE RAVEN

Continuing along the same curve, we finally reach the little constellation Corvus (Apr.-May).

THE LITTLE LION

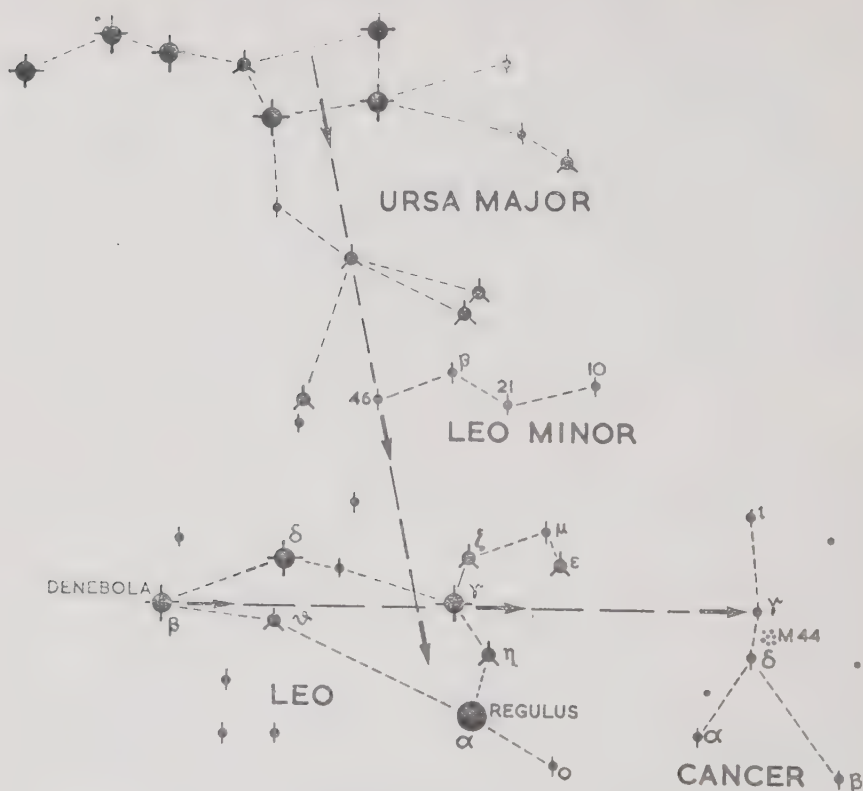
A line from the middle of the quadrangle of Ursa Major, through the third magnitude star ψ (*psi*), directly below, brings us to the star 46 of Leo Minor (Feb.-July). Only four of its stars are brighter than magnitude 5, and it is rather inconspicuous.

THE LION

Farther on, however, just beyond Leo Minor, lies the much more spectacular group of Leo (Mar.-May). The distinguishing feature of Leo is the 'sickle' or 'question mark' formed by the stars directly above Regulus, the brightest star of the constellation. This star is also known as Cor Leonis, the Heart of the Lion.

Denebola (β [*beta*] Leonis) forms the Lion's tail, and this is exactly what its Arabic name means.

Leo is one of the Zodiacal constellations, and Regulus is almost exactly on the ecliptic. It is one of the very few constellations which more or less resemble the creature they are supposed to represent, and it is not difficult to see a crouching lion outlined by the stars of this constellation.



Map 2. Ursa Major, Leo Minor, Leo and Cancer

THE CRAB

If we draw a line from β (*beta*) Leonis to γ (*gamma*), and continue beyond γ for about the same distance, we reach the magnitude 4 star γ (*gamma*) in Cancer (Feb.-May). The five brightest stars of this constellation, all of magnitude 4, form an inverted Y, and there is little about it that is remarkable, were it not for the cluster of stars marked as M 44 on the map.

To the naked eye this cluster is visible as a hazy spot, and on an exceptionally clear night a few stars of magnitude 6 can be distinguished. The astronomer Messier catalogued all such hazy spots in the sky which we now call nebulae and clusters. This particular one was number 44 in his list.

M 44 is called Praesepe, which means a Manger, and in the old star maps the stars γ (*gamma*) and δ (*delta*) above and below it, were named Asellus Borealis and Asellus Australis—the Northern Ass and the Southern Ass, two beasts of burden supposed to feed from the manger. Nowadays the cluster is better known as the Beehive, because of its shape. There are about four hundred stars in it, but most of them are visible in powerful telescopes only.

THE CHARIOTEER

During the winter months, the stars δ (*delta*) and α (*alpha*) Ursae Majoris help us find a few more constellations. A line through these two stars points directly at Capella, a bright, yellowish star in Auriga (Nov.-May). The name Capella means the Little She-Goat, but there is little in this star to resemble that, because it is a giant star, about 16 times the diameter of our Sun, and emitting 150 times as much light.

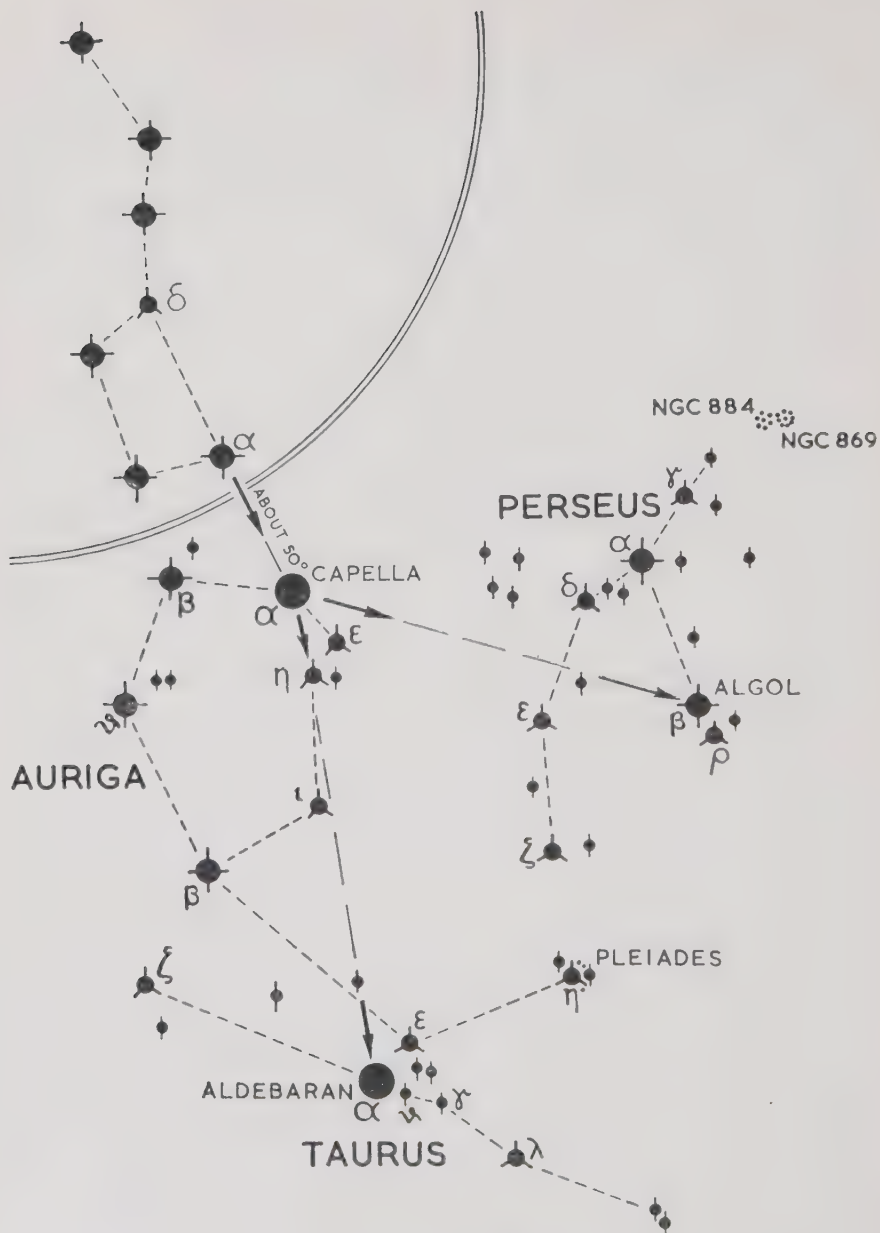
Capella is a distinctly yellow star, but it has not always been so. The Greek astronomer Ptolemy (A.D. 150) describes it as red, and so did Al Fagani (10th century), and Riccioli (17th century).

The three little stars underneath Capella are called the Kids, and one of these, again, is by no means what its name implies it to be. It is a giant star, which, were it in the place of the sun, would reach far beyond the orbit of Saturn. This is the star ϵ (*epsilon*), which is also remarkable because its brightness varies between mag. 3 and mag. 4 during a period of 27 years.

The constellation Auriga was usually drawn as an irregular pentagon on old star maps, but now the modern star atlases show it as a quadrangle, the lowest of the five stars having been assigned to the next constellation, Taurus, with the result that Auriga now has no star in it which is designated by the letter γ (*gamma*).

THE BULL

The line from α (*alpha*) over η (*eta*) Aurigae points roughly at Aldebaran, the brightest star in Taurus (Dec.-Apr.). This reddish star lies in the V-shaped cluster of stars known as the Hyades. There are about 50 stars which belong to this group. They all travel through



Map 3. Auriga, Perseus and Taurus

space at an unbelievable speed, which is the same for every one of these stars, and they all travel in the same direction. They are a family of stars, but Aldebaran itself does not belong to it. It is much nearer to the sun than the other stars of this cluster, and merely happens to be in the same direction as seen from our position.

Close to α (*alpha*) is the 4th mag. star θ (*theta*) which is visible as a double star on clear nights, even without using a telescope or opera-glasses.

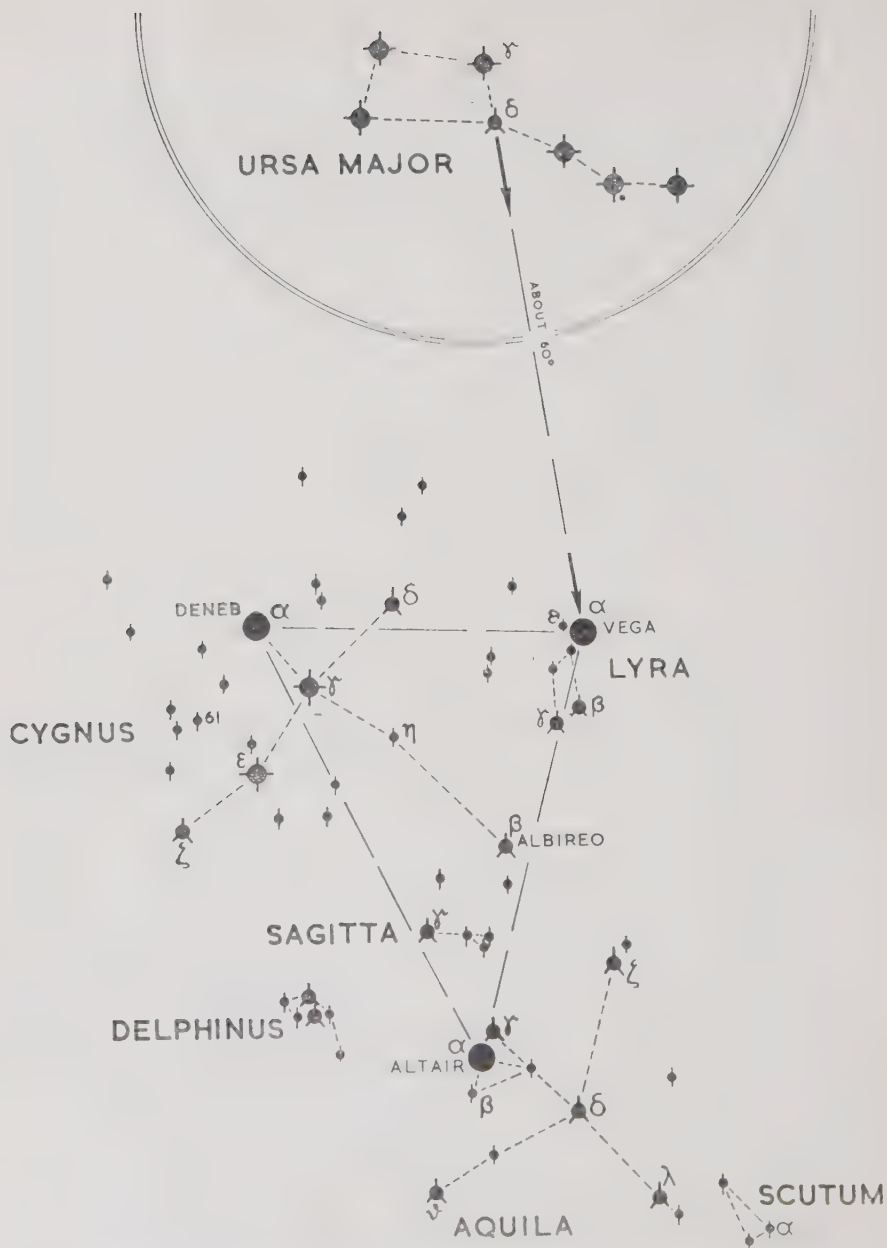
Much better known than this group, however, are the Pleiades, also called the Hen and her Chickens, or the Seven Sisters. η (*eta*) Tauri is the brightest among them, and is called Alcyone. The names of the other stars are: Atlas, Pleione, Asterope, Celaeno, Maia, Electra, Merope and Taygeta. They are all about 800 times the size of the Sun, and, like the Hyades, have a common motion through space. Usually the naked eye can see only six of the stars in this cluster, but the telescope reveals that there are about six hundred of them.

PERSEUS

The stars β (*beta*) and α (*alpha*) Aurigae point at Algol in Perseus (Oct.-Apr.). Its name means Demon, and very aptly it is named, too. Every 69 hours this star diminishes in brightness, and, from its usual magnitude 2.3 it sinks to mag. 3.5 within about 5 hours. After a short while, however, its brightness starts increasing, and after another five hours it has regained its usual brilliance.

For hundreds of years this star had been observed before the cause of its variability was discovered: Algol is not a single star, but consists of two stars which are of about the same size. One of them is fairly bright, and the other is almost dark. These two revolve around each other, the dark one eclipsing the other at each revolution. We know a great number of similar stars now, dark eclipsing variables, as they are called, but Algol is the most striking example of this type of star.

The stars α (*alpha*) and γ (*gamma*) show us the way to another of these hazy patches in the sky, but this time we find two star clusters, almost touching one another. On clear nights these are visible to the naked eye, but binoculars show us here one of the most beautiful objects in the sky. (See Plate XVI.) These two, like the Pleiades and the Hyades, are called *open clusters*, which all contain several hundred stars and are within the Milky Way system at distances varying from 500 to 5,000 light-years.



Map 4. Cygnus, Lyra, Aquila, Sagitta, Delphinus and Scutum

THE LYRE

The stars γ (*gamma*) and δ (*delta*) of the Great Bear indicate the direction of Vega in the constellation Lyra (Apr.-Jan.). Vega itself is a circumpolar star at the latitude of London, but the rest of the constellation is not. Vega is a bluish white star, the brightest one north of the celestial equator, and is a very conspicuous object. Keen eyes will be able to see that the star ϵ (*epsilon*), closely to the left of Vega, is a double star, the two components being of magnitudes 4.5 and 4.9 respectively. They are 3' 30" apart, which is about a third of the distance between Mizar and Alcor. Each of these two stars is double again, but this can be seen only in a fairly large telescope.

Another remarkable star is β (*beta*). Here, two luminous stars circle around each other, and usually we see it as a star of magnitude 3.4, this brightness resulting from the light of both the stars combined. Each star, however, eclipses the other once in every revolution, and we can see only the light reaching us from the star which happens to be in front. This results in an apparent diminution of its brightness, and as the stars circle around each other in the period of 12 days and 22 hours, we see the combined light growing dimmer twice in that interval.

Vega belongs to the Great Summer Triangle, which is above the horizon for the whole of the night from May to August. The other two stars in this triangle are Deneb in Cygnus and Altair in Aquila. All three stars are of the first magnitude, and are easy to locate once the position of one of them has been found.

THE SWAN

Deneb, a little nearer to the Pole Star than Vega, and to the East of it, belongs to the constellation Cygnus (May-Jan.). As its name implies, it represents the tail of the flying swan. The head is β (*beta*), Albireo. This is a very fine double star, but one needs binoculars to see it as such. The contrast between the two components is really grand, the mag. 3 star is a bright orange, and its 6th magnitude companion is of a rich, blue colour.

The 4th mag. star 61 is also a double, but this one is interesting for quite a different reason. 61 was the first star whose distance was actually measured. In 1838, Bessel succeeded in detecting a slight shift in the position of this star, as compared with the neighbouring ones which are much farther away. This slight change of its position,

due to the motion of the Earth around the Sun, can be observed only with comparatively near stars, and its exact measurement, in this case, led to the result that 61 Cygni is about 11 light-years away from us.

THE EAGLE

To the south of Deneb and Vega, completing the Summer Triangle, is Altair, the brightest star in Aquila (June-Dec.). It is of a fierce, white colour, and is actually about ten times as bright as our Sun.

η (*eta*) Aquilae is another variable star, but this time there is no companion star to eclipse it. The star itself changes in brightness; one is almost inclined to say the star is breathing. For about 40 hours it shines steadily at mag. 3.5, and then it gradually becomes fainter during the following 66 hours, until it reaches mag. 4.5 and remains so for about 30 hours, until its brightness increases again. The whole cycle has a duration of 7 days, 4 hours, and 14 minutes.

It is interesting to compare the colours of γ (*gamma*) and ζ (*zeta*) in this constellation. The first is golden yellow, and the other of a greenish colour.

There are three small asterisms dotted about Aquila, all consisting of rather faint stars, and none of them of much interest. The names of these are: Sagitta (the Arrow), Delphinus (the Dolphin) and Scutum (the Shield).

ANDROMEDA

The stars α (*alpha*) and β (*beta*) Cassiopeiae point directly at γ (*gamma*), the easternmost star in Andromeda (June-Mar.). It is a fairly large constellation, with three mag. 2 stars in it. The two little stars μ (*mu*) and ν (*nu*) lead us to M 31, which is another hazy spot in the sky, though of a different type this time.

M 31 is usually called the Great Nebula in Andromeda, and it is just visible to the naked eye on a clear, moonless night. Nowhere else in the sky can the naked eye penetrate farther into space than here, for this nebula is $1\frac{1}{2}$ million light-years away from us.

It is another galaxy, like our Milky Way, and it is just about the same size. Like our own Galaxy, so is this little patch made up of millions and millions of individual stars, and our biggest telescopes can just distinguish those which are in the outer parts of the spiral. Our Sun, at that distance, would be completely invisible. Although this is the



Map 5. Cassiopeia, Andromeda, Pegasus, Aries, Pisces, Aquarius, and Triangulum

only nebula of its kind which is clearly visible to the unaided eye, our large telescopes have recorded millions of similar island universes already, and every year adds new ones to the list.

Below the eastern end of Andromeda is the little constellation Triangulum (The Triangle), and beyond this we find another of the Zodiacal constellations:

THE RAM

This is easy to find, as its main stars, α (*alpha*) (Hamal) and β (*beta*) are the brightest ones in the vicinity. A little over 2,000 years ago, Aries (Sept.-Mar.) marked the point in the sky where the sun crossed the equator from South towards North, thus marking the beginning of the astronomical year, which occurs on 21 or 22 March every year. Aries lent its name to the first of the twelve 30-degree divisions of the Zodiac, which we still call the Signs. The intersection of the equator with the ecliptic is called the *First Point of Aries*, and the precession has moved this into the constellation Pisces, to a point half-way between the stars ω (*omega*) and 33.

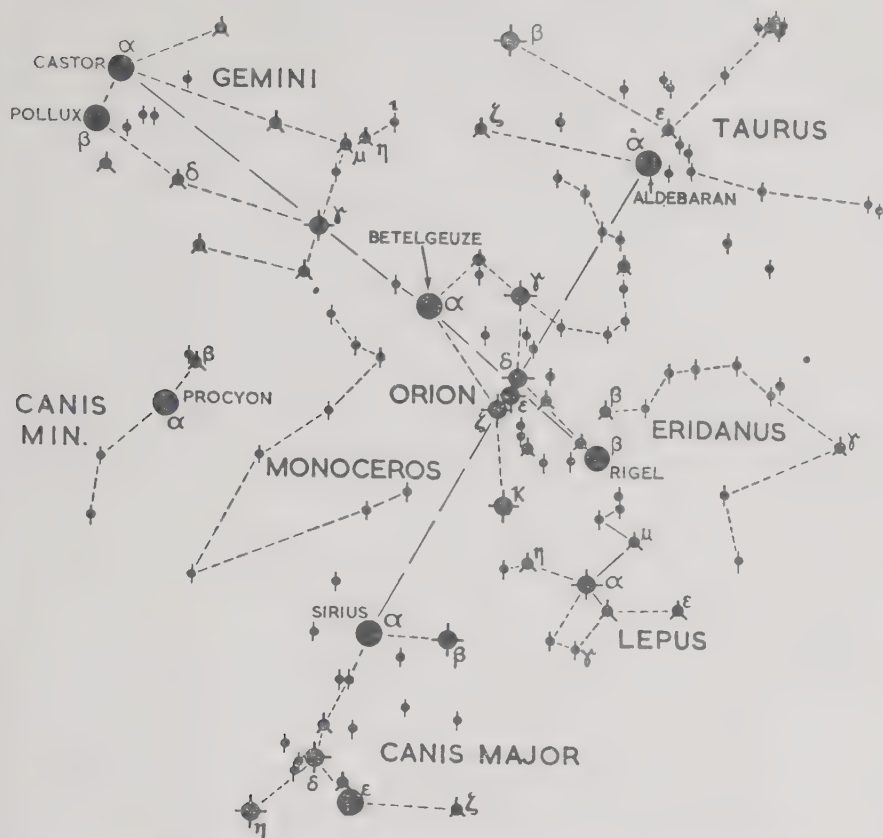
THE WINGED HORSE

The star Alpheratz (α Andromedae) helps to make up the Great Square of Pegasus (July-Feb.). Both its sides point at the Pole Star, and, together with Andromeda, it looks like a giant edition of the Great Bear. The inside of the square seems quite empty usually, but on an exceptionally clear night, over 30 stars can be counted inside it. Below Pegasus lies the Zodiacal constellation Aquarius, the Water-bearer. Its most conspicuous asterism is the little Y-shaped group of stars east of α (*alpha*), which is called the Waterjug, and which lies almost exactly on the celestial equator.

THE HUNTER

During the winter months, we can see the most spectacular constellations in the whole sky; foremost among them is Orion (Dec.-Mar.). In this we find two stars of the first magnitude and no less than four of the second.

Betelgeuze (α Orionis) is a reddish giant star with a diameter larger than that of the orbit of the planet Mars. It is one of the pulsating



Map 6. Taurus, Orion, Canis Major, Canis Minor and Gemini

stars, varying in brightness from mag. 0.5 to mag. 1.4. This change in its brilliance is quite easy to notice if we compare Betelgeuze with Rigel (β Orionis), which is of mag. 0.3. At its brightest, Betelgeuze is about the same as Rigel, but when approaching minimum it is more than one magnitude fainter.

Below Orion's belt we find three somewhat fainter stars, the middle one of which is situated in the centre of the Great Nebula in Orion. This gigantic cloud of incandescent gas is plainly visible to the naked eye as a greenish spot, and telescopes show that this nebulosity extends over the greater part of the whole constellation.

THE GREATER DOG

The three stars of Orion's belt point at Aldebaran in Taurus on one side, and on the other at Sirius in Canis Major (Feb.-Apr.). Sirius is the brightest star in the sky which can be seen from our latitude. It is also one of the nearest stars, only eight and a half light-years distant.

Sirius has a companion star, and the two revolve around each other. The discovery of this companion was one of the triumphs of astronomy. Minute oscillations of Sirius about its mean position led to the assumption that there must be a second star to cause such a movement, and the orbits of the two were computed. Twelve years later, in 1862, Alvan Clark actually saw this star when he looked at Sirius with a new 18-inch telescope which he had built for the observatory at Chicago. This companion is one of the most remarkable stars known. It has about the same mass as our Sun, but its diameter is only about three times that of the Earth, which means that one cubic inch of the material of this star weighs as much as a ton.

Sirius is bright enough to cast a perceptible shadow on moonless nights, and it makes its first appearance in the eastern sky before sunrise early in August, at the time of the annual flooding of the Nile, an extremely important event in the life of the country of Egypt, and this time of the year is still referred to as the Dog Days.

THE LESSER DOG

East of Orion we find the little constellation Canis Minor (Jan.-May). Procyon, its brightest star, forms with Sirius and Rigel a right angle, Sirius being at the apex.

Procyon is a deep yellow star, its colour becoming particularly noticeable when it is compared with the fierce, white light of Sirius. There is only one other star in the constellation which is brighter than mag. 4, yet it is very conspicuous, as the two main stars of the Little Dog are surrounded by a wide belt in which there are only very faint stars.

THE TWINS

A line from β (*beta*) Orionis over α (*alpha*) brings us to the large rectangle of Gemini (Dec.-Apr.). The constellation is marked by two very bright stars, and these have the names of the twins of Greek myth-



PLATE IV. German Sundial made in 1702. This instrument not only indicated the time of the day, but also the declination of the sun.

By courtesy of the Curator of the Museum of the History of Science, Oxford

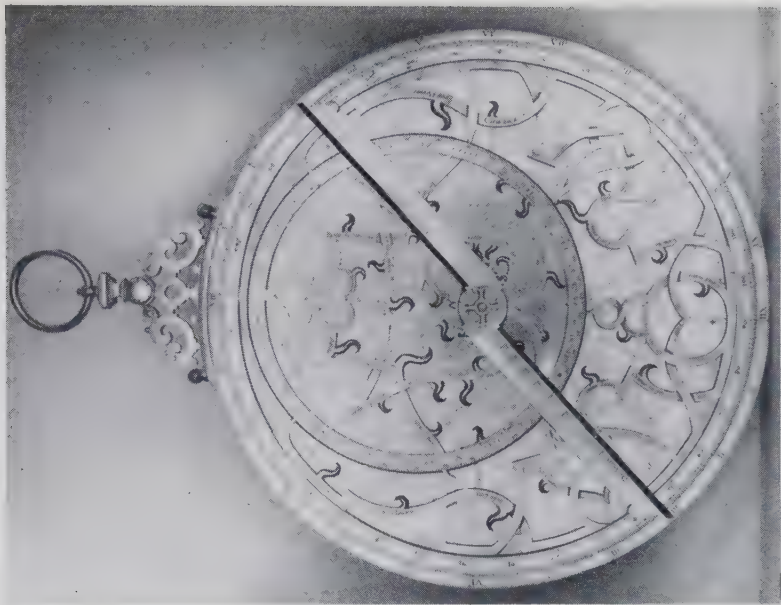


PLATE V. Front of sixteenth century Astrolabe, constructed for latitudes 42° – 46° North. The ecliptic and the principal stars are represented on the movable rete, while underneath the graticule represents the horizon with the circles of altitude and azimuth.

By courtesy of the Curator of the Museum of the History of Science, Oxford

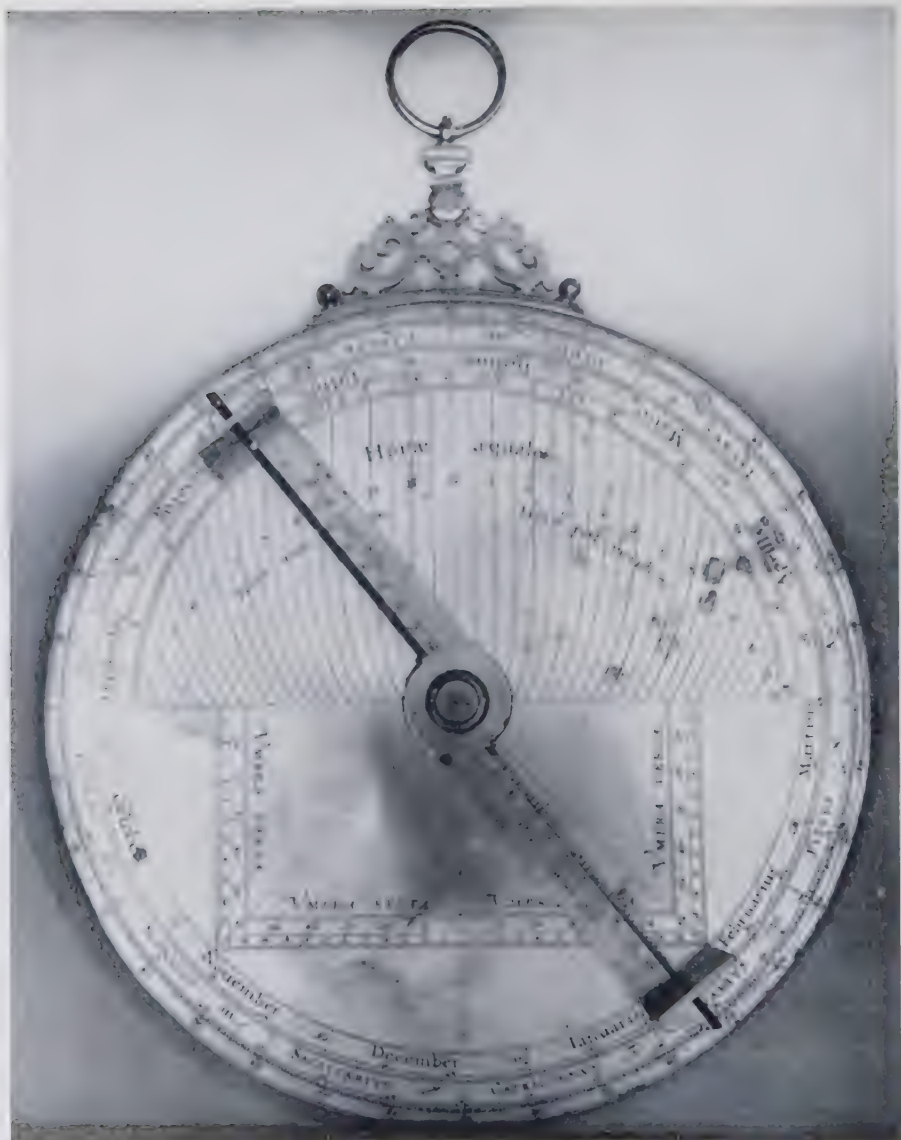


PLATE VI. Back of sixteenth century Astrolabe. The scales near the edge allow the position of the sun to be determined for any day of the year. The upper half of the centre portion is a sundial, and the scales in the lower half were used for measuring the altitude of mountains or towers. The 'label' with its sightvanes was used for measuring the altitude of stars.

By courtesy of the Curator of the Museum of the History of Science, Oxford

ology—Castor and Pollux (α and β). Castor is quite a remarkable star: a telescope shows two stars fairly near to each other, and a third one a little farther away. They all revolve around their common centre of gravity. It has been found, however, that each of these three stars is a double star, but no telescope is able to separate the components as they are much too close together. Castor, therefore, actually consists of six stars and his twin brother, Pollux, is not outdone by him, because he, also, consists of at least six stars, and there are also a few other stars, though rather faint ones, near to it. But they do not belong to the multiple system of Pollux; they merely happen to be in the same line of sight.

The contrast of colour between Castor and Pollux is quite remarkable. Castor is almost pure white, while Pollux is orange in colour.

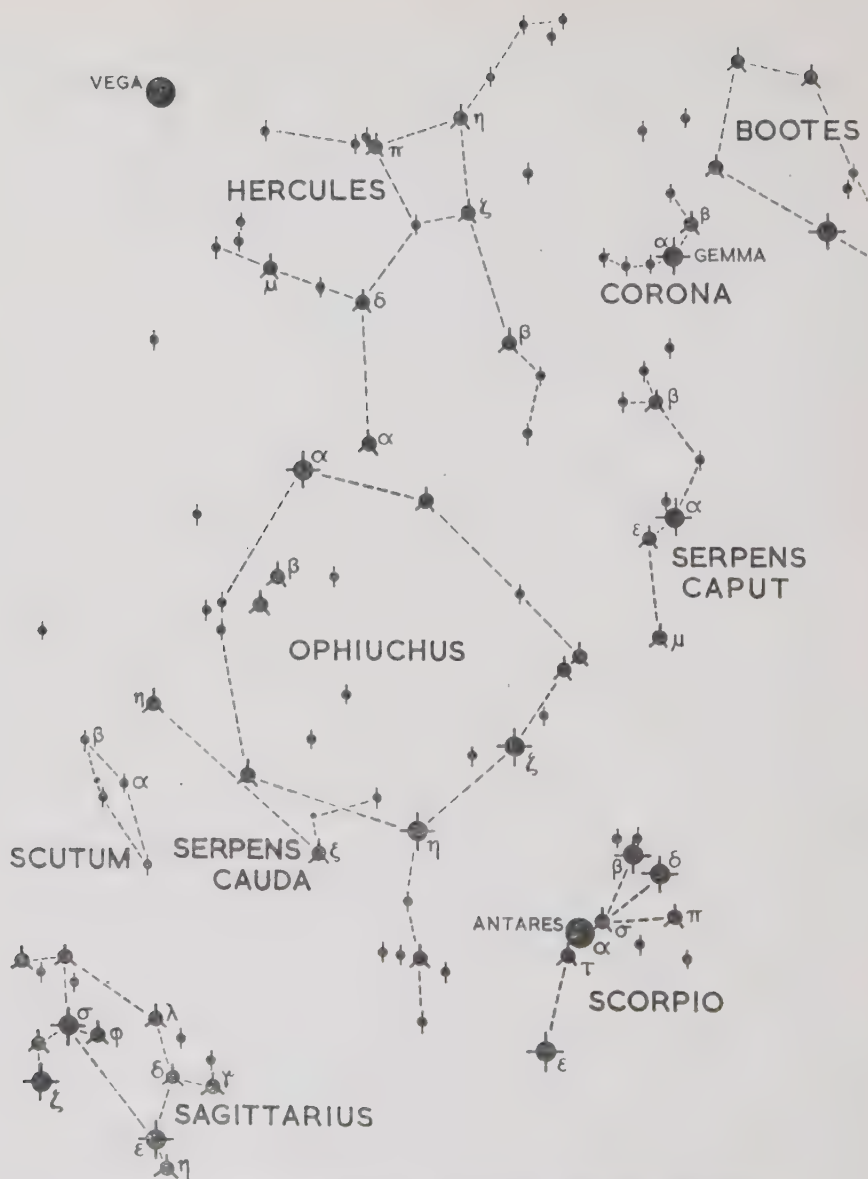
On the other end of the rectangle of Gemini we find the stars μ (*mu*) and η (*eta*), and the star No. 1. This mag. 4 star lies almost exactly at the most northerly point of the ecliptic, and thus marks the position of the Sun on the longest day of the year.

Almost every star in Gemini has been found to be a double star, although many of them can be distinguished as such only in very large telescopes, and it certainly was a bit of a coincidence that this group of stars should have been named the Twins.

Orion with the Dogs, the Bull and the Twins are the Winter Constellations, and they are also the most spectacular ones in the sky. Their brilliance makes it easy to overlook the few faint asterisms which lie near them. There is Eridanus (the River) on the Western side of Orion, Lepus (the Hare) to the South of it, and Monoceros (the Unicorn) to the East. They all consist of rather faint stars only, and, with the exception of Lepus, are not easy to delineate.

THE CROWN

On the eastern side of Bootes we find the little constellation Corona (Apr.-Nov.), which is one of the most striking ones in the northern sky, although only one of its stars is brighter than mag. 4. It is not difficult to imagine this semicircle of stars to represent a crown, with the brightest star in a position which would be taken by the most valuable gem which is set in it, and Gem is what the star's name, Gemma, means.



Map 7. Corona, Hercules, Ophiuchus, Serpens, Sagittarius and Scorpio

HERCULES

Half-way between the Crown and the blue-white star Vega, the main star of the Lyre, lies a little quadrangle of stars which is part of the constellation Hercules (May-Nov.). This is a large, inconspicuous group which it is not easy to identify.

On the line from η (*eta*) to ζ (*zeta*) lies M 13, yet another hazy patch of light, which is only just visible to the naked eye if the night is clear and moonless. If this is seen through binoculars, or through a small telescope, it looks like a huge sphere filled with thousands of stars. There are many similar accumulations of stars like this one, and they are called *globular clusters*. These surround the Milky Way system on all sides, and are therefore farther away from us than are the open clusters. This particular one, consisting of about 30,000 stars, is 36,000 light-years distant. It is one of the most beautiful objects of its kind in the sky, and it is well worth the trouble to try and find it, and see it through field-glasses or a small telescope. (See Plate XVII.)

THE SNAKEBEARER AND THE SERPENT

Below Hercules are two constellations which are somewhat mixed up with one another. They are Ophiuchus and Serpens (June-Sep.). Serpens has the distinction of being the only constellation in the sky which consists of two parts which are unconnected with each other. On the western side of the Snakebearer is the Head of the Serpent, and on the eastern side the Tail of the Serpent. The Latin names of the two parts are Serpens Caput and Serpens Cauda. The brightest star of this constellation α (*alpha*) has the unusual sounding name Unuk al Hay, which is of Arabic origin and merely means Neck of the Serpent.

α (*alpha*) Ophiuchii has a name which is equally unusual, Ras Alhague, which somewhat reminds one of some black-bearded eastern despot. The most remarkable star in this constellation is γ Ophiuchii, the easternmost of three mag. 4 stars south-east of α (*alpha*).

Quite a small telescope will reveal that this is a double star, the two components revolving around their common centre of gravity. From their motions it could be deduced that there must be a third, obviously dark body revolving with the system, and it is here where we have the only direct evidence that there are other bodies in the Universe which can be compared with the planets of our Sun.

THE ARCHER AND THE SCORPION

South of the Snakebearer, and on either side of it, we find Sagittarius (Aug.-Sep.) and Scorpio (June-July). Both of them are fairly impressive constellations, containing several bright stars, and both belong to the Zodiac. But neither of them attains an altitude above the horizon which is sufficient to lift them out of the haze which usually makes stars near the horizon difficult to see, although Antares (α Scorpii), a reddish giant star, can usually be seen quite well.

THE REMAINING CONSTELLATIONS

We have here considered in detail only the principal constellations, but there are about another dozen or two which are visible at one time or another. They all consist of rather faint stars, and their recognition will be possible only after the principal constellations are remembered. Many of these faint ones are marked on our star map at the end of the book, which could be copied on to a piece of stout cardboard, so that it is not necessary to take the book itself when we are trying to find the constellations.

In the Appendix we also find a diagram of a mask which goes with this star map, and this, too, can be cut from cardboard. The heavy lines on the map and on the mask must be made of exactly the same diameter, and the shaded portion of the mask, which is to be removed, is bounded by a circle which represents the horizon. The diameter of this circle, as well as the position of its centre, depends on the latitude from which we make our observations, and in a later chapter we shall see how this circle can be constructed.

If this mask is placed on top of the star map, so that the date on the mask is opposite the time of observation marked on the map, then the part of the map visible in the circular aperture of the mask shows those stars which are visible at the time for which it has been set. The edge of the aperture represents the horizon, and the cardinal points are marked on it. The mask shown in the Appendix can be enlarged and cut out, and it will show the aspects of the sky for places in a latitude of 52° , which is approximately the latitude of London.

When comparing our map with the sky, it should be held in such a position that the direction in which we want to look appears at the bottom of the mask. In this way it is possible to find the constellations quite easily, even if they are the faint ones, as they will thus appear on the map in exactly the same position as they are actually seen in the sky.

6

The Revolving Heavens

UP TO now we have been referring to the positions of stars or of the Sun in the sky in rather vague terms only, and it is time to consider this problem in more detail. In order to accurately describe the position of a star, we need a system of co-ordinates as we use it on Earth to describe the position of a town or of a ship at sea by stating its latitude and longitude. The latitude is the angular distance, expressed in degrees, from the equator, and the longitude is the distance, again measured in degrees, from the meridian of Greenwich. A similar system can be used to describe the position of a star on the celestial sphere, as it appears to an observer on Earth. As all distances can thus be expressed in degrees the actual distances in miles, light-years, etc., measured along the surface of the sphere do not enter into the calculations at all, and the diameter of the sphere is unimportant, too.

The easiest way to describe a star's position is to refer it to the observer's horizon. This horizon, however, must be the mathematical one, and not the natural horizon with its ups and downs of houses, trees, mountains and distant hills. This mathematical horizon exists only at sea, where there is nothing to obstruct it. Everywhere else the natural horizon is usually several degrees above the mathematical one.

The altitude of the star above the horizon, expressed in degrees, is one of the co-ordinates, corresponding to the latitude on Earth. It is measured along a vertical circle passing through the zenith and the star, meeting the horizon directly below the star.

The other measurement, corresponding to longitude on Earth, is called the *azimuth*, and this is measured along the horizon, from the South-Point to the intersection of the vertical circle through the star with the horizon. The South-Point, of course, lies on the celestial meridian of the observer. On the Earth, a meridian is a circle passing

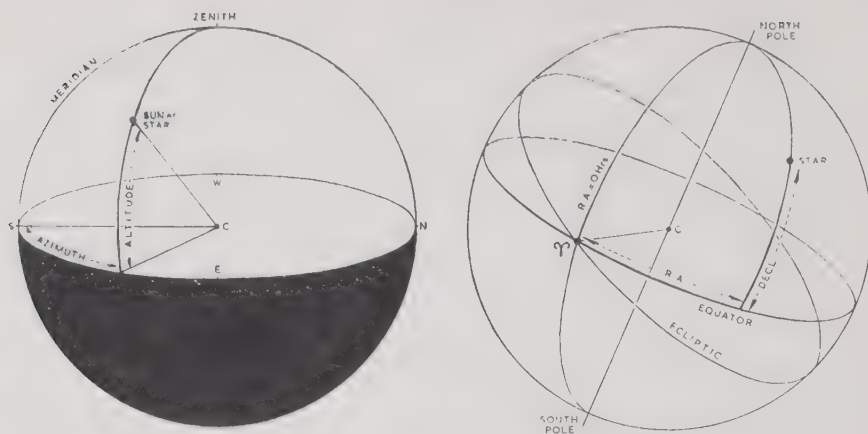


Fig. 10. The two systems of co-ordinates used in astronomy

through the two poles and through the position of the observer. The celestial meridian also passes through the two poles, and through the observer's zenith, cutting the horizon in the North- and South-Points. Astronomers usually measure the azimuth from the South-Point, and an azimuth of 30 degrees towards East is written: S 30° E. A different method is used by navigators, who reckon azimuth from 0 to 360 degrees, starting from the North-Point, and going over East, South, West, and back to North.

Useful as this system of co-ordinates is, it nevertheless tells only half the tale, for the position of a star as given by this system is correct only at a specific time, owing to the rotation of the Earth, and it also depends, as we shall see presently, on the observer's position on Earth.

To make possible the fixing of a star's position with respect to others, as it would be necessary for the purpose of making star maps, we must, therefore, find a reference system which moves around with the celestial sphere.

The celestial poles and the equator are best suited as starting-points of such a system, but all we are able to measure is the angular distance of a star from either of these, and we shall need one more measurement to fix its position, measured from some arbitrary circle, like the Greenwich Meridian on Earth.

Astronomers have chosen as starting point for this measurement the intersection of the ecliptic with the celestial equator. Of the two alternatives, the one which the Sun occupies on 21 March was selected,

and this is the First Point of Aries, denoted by the sign γ . The semicircle passing through this point and through the two celestial poles is, so to speak, the celestial Greenwich Meridian.

This semicircle coincides with the observer's meridian once every day. As the star sphere rotates, it will have moved towards the West after, say, an hour, and another, similar, semicircle then coincides with the meridian. The distance between the two, measured along the equator, is 15 degrees, and as this measurement is so closely related to time, it is conveniently reckoned in hours, minutes and seconds. It also determines the relative times of the rising of the stars, and for this reason it is called *rectascension*, abbreviated R.A.

The semicircle passing through the First Point of Aries has the R.A. 0 hrs., the one coinciding with the meridian one hour afterwards has the R.A. 1 hr. and so on. It is obvious that this measurement is made anti-clockwise, that is from γ towards the East.

The second co-ordinate on the celestial sphere is called *declination*, abbreviated *decl.*, and it is measured in degrees, along one of the hour circles, either towards North or towards South from the equator. North declination is usually written + so many degrees, and south decl. — so many degrees. The star marked in our right-hand diagram of Fig. 10 has a R.A. of about 3 hrs., and its decl. is about 50° .

The two systems of reference, let us call them the terrestrial and the celestial systems, naturally exist simultaneously, and we must now consider how they are related to each other.

An observer, stationed at the Earth's North Pole, would have the celestial North Pole right overhead, that is, celestial pole and zenith are the same point in the sky. The celestial equator coincides with his horizon, but if the observer moves towards the South, the celestial equator will rise above the horizon in the South, and the celestial pole will approach it in the North.

When he reaches the equator, he will have the celestial equator, or at least one point of it, overhead, and the two celestial poles are on the horizon.

The position of the pole and equator in the sky obviously depends on the latitude from which they are observed, and from the study of Fig. 11 it will be found that the relationship is quite simple: the altitude of the pole above the horizon is equal to the latitude, and this same angle appears again as the distance between the zenith and the celestial equator, measured along the meridian. The altitude of the equator, measured also along the meridian, as well as the distance of the pole from the zenith, is 90° minus the latitude.

same as the hour of R.A. which happens to be on the meridian, and this is also called the Sidereal Time.

At the end of the book we find a table headed 'Sun and Sidereal Time at Noon for the Meridian of Greenwich'. From this table we can find the hour angle of γ on every day of the year at noon. For any other time of the day we have to add the number of hours passed since noon, and, as Sidereal Time gains four minutes every day on Greenwich Mean Time, we have to make an adjustment by adding 10 seconds for every hour which has passed since noon, and 1 second for every six minutes. This correction we then express as a decimal fraction of a minute, which is then added to the figures. The table gives the values for every fourth day only, and on intermediate dates we find the Sidereal Time at noon by adding 3.9 minutes for every full day which has passed since the last tabulated date.

If we want to know the Sidereal Time at 21.00 hrs. on 21 October, 1956, we find from the table that the Sidereal Time at noon was 13 hrs. 59.6 mins., and we can now write down the little sum:

	<i>hrs.</i>	<i>mins.</i>
Sidereal Time at noon	13	59.6
Hours since noon	9	00
Correction		1.5
Sidereal Time at 21.00 hrs.:	23	01.1

We thus know that on this particular day at 21.00 hours (9 P.M.) the semicircle of the R.A. 23 hrs. 1.1 mins., is on the meridian of Greenwich, and from a star atlas or from our star map we can find out which constellations are due South at that time. The hour angle of Aries (short for First Point of Aries), is, of course, the same.

The hour angle of a star is related to the Sidereal Time. A star which has the R.A. 5 hrs. will cross the meridian 5 sidereal hours after Aries, and its hour angle, therefore, is always 5 hours less than that of the First Point of Aries.

If the hour angle (in future abbreviated: H.A.) of γ is smaller than the R.A. of the star, 24 hours must first be added to the H.A. before subtracting the R.A.

The Sidereal Time is tabulated for the meridian of Greenwich, and all our calculations apply to this only. For any place either east or west of Greenwich, the H.A. of Aries and that of the star are different.

The meridian marked in Fig. 12 represents that of Greenwich, and the Sidereal Time is 3 o'clock. A star with the R.A. of 08.00 hours,

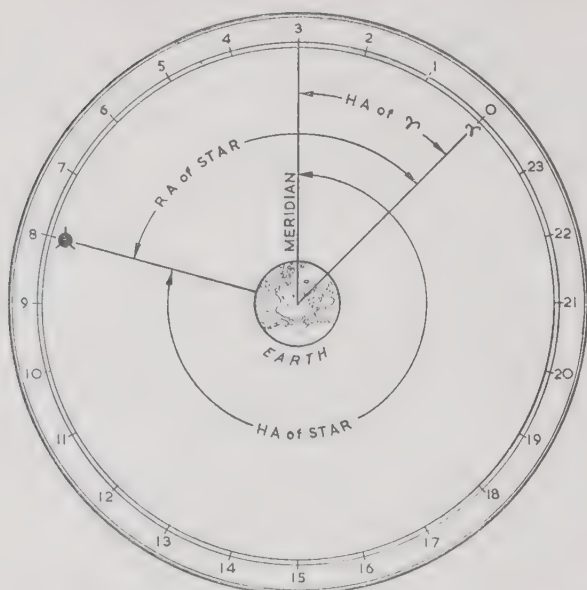


Fig. 12. Relationship between hour angle and longitude

therefore, has the H.A. of 19.00 hrs. (03.00 hrs. plus 24.00 hrs. = 27.00 hrs. minus 08.00 hrs. = 19.00 hrs.).

At a place 45° West of Greenwich, the First Point of Aries is directly on the meridian of an observer at that longitude. The H.A. of Aries and that of the star are both 3 hours less, as each hour of R.A. equals an angle of 15 degrees, and $45^\circ = 3$ hours. The H.A. of Aries for that longitude is therefore 00.00 hours, and that of the star is 16.00 hrs. For places east of Greenwich, the longitude, converted into time, must be added to the H.A.'s calculated for Greenwich.

With these considerations we can calculate the H.A. of a star at any time and for any place on Earth, and such a calculation would look like this:

	<i>hrs.</i>	<i>mins.</i>
Greenwich Sidereal Time:	03	00
Plus 24 hrs.	24	00
	27	00
R.A. of star: minus	08	00
Greenwich H.A. of star:	19	00
Longitude West (converted into time): minus	03	00
H.A. of star:	16	00

There still remains another complication, however: as noon is defined as the time when the Sun is due South, it follows that a place 15 degrees East of Greenwich has noon an hour earlier than people on the Greenwich Meridian, and those 15 degrees West of it have it an hour later.

For the sake of convenience, the Earth has been divided into 24 zones, and the time used in each of them differs by one hour from the zones on either side of it. Each zone is 15 degrees wide, and the British Isles are in Time Zone O, which means that our Civil Time is identical with Greenwich Mean Time (except, of course, during the months when Summer Time is in force). Time Zone plus 1 begins at Longitude $7\frac{1}{2}$ degrees East of Greenwich, and extends to longitude $22\frac{1}{2}$ degrees East.

Within these limits, all countries or ships at sea use a time which is one hour in advance of Greenwich Mean Time (in future abbreviated G.M.T.). Farther towards the East we have time zones up to plus 12, and towards the West of Greenwich are the time zones in which the time used is always less than G.M.T., that is Time Zones minus 1 to minus 12.

Time Zones minus 12 and plus 12 are, of course, identical, but along the centre of this zone runs a line known as the *date line*, and every ship crossing it either gains or loses a day. The time throughout this zone is the same, say, 3 A.M., and, as Greenwich Mean Time differs from the time in this zone by 12 hours, the G.M.T. at that moment is 15.00 hrs., or 3 P.M. Assuming that the date at Greenwich is 12 March, we can go towards the West and cross all the 'minus' zones, until we reach Zone minus 12, and the date and time there is 12 March, 03.00 hrs. Going towards the East from Greenwich, we come across all the 'plus' zones, and when we come to Zone plus 9, we find that it is midnight there. The remaining time zones, including the western half of Zone plus 12, have already changed the date to 13 March. Although it is 3 A.M. throughout the whole of Zone 12, it is 12 March in the eastern half of it, and 13 March in the western half.

By crossing the date line we either have to add one day or subtract one day from the date used previous to the crossing, and, of course, alter the day of the week, too. A cunning missionary living in those parts of the world was said to have contrived by suitable crossings of the date line to have 104 Sundays every year, and his neighbour, a shrewd trader, managed to have none at all.

The zone time, of course, may differ by as much as half an hour from the true time indicated by the H.A. of the Sun if the observer is at

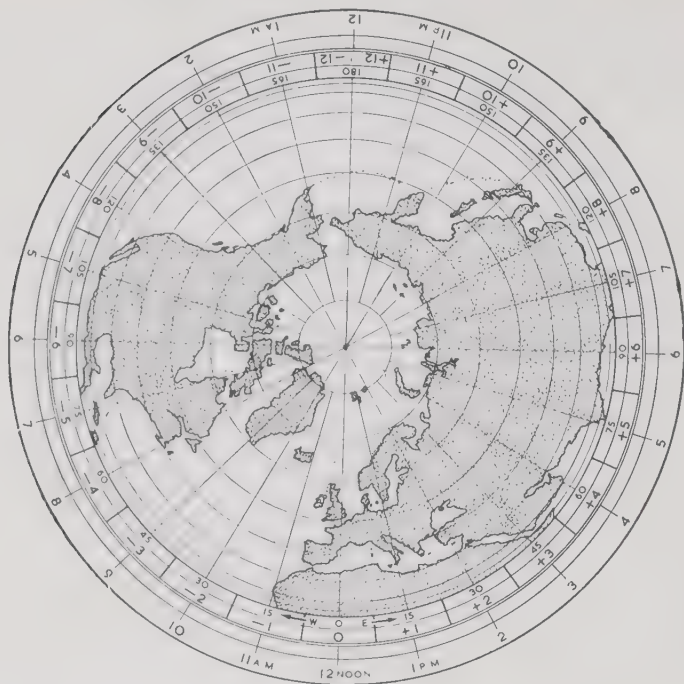


Fig. 13. Time and longitude. The inner circle of figures denotes longitudes east or west of Greenwich, and the second circle marks off the different time zone. If these two circles, together with the map at the centre, were rotated against the outer circle of hours so that the Greenwich Meridian (longitude 0) points at the G.M.T. of the moment, represented by the figures in the outer circle, then each meridian indicates the zone time of its particular zone of which it is the central meridian.

one of the boundaries of his zone. If he determines time with the aid of a sundial, or by observing the stars, he obtains what is known as Local Mean Time, which differs from the zone time by 4 minutes for each degree the observer is either east or west of the central meridian, and it differs, at the same time, from G.M.T. by 4 minutes for every degree he is either east or west of the Greenwich Meridian.

Taking all this into account, we can write down our sum for the H.A. of a star again. This time the method of calculation applies universally, wherever we are on Earth, and, as the H.A.'s of either the stars or of

Aries are constantly required, it is best to commit the procedure to memory.

As an example we shall calculate the H.A. of Procyon (α Canis Minoris) at New York, on 9 March 1954 at 9.30 P.M. local time.

First of all we write down the Local Zone Time, and by adding or subtracting the Zone Difference we obtain the G.M.T. From this we find the time interval since noon, which is converted into an interval of Sidereal Time by adding 10 seconds for every hour which has passed since noon, and 1 second for every 6 minutes. To the result we add the actual Sidereal Time at noon and we thus obtain the Greenwich Sidereal Time of the moment. This is converted into Local Sidereal Time by subtracting our longitude after converting it to time, remembering that $15^\circ = 1$ hour, and $1^\circ = 4$ minutes. (If our Longitude is East, we have to add it to the Greenwich Sidereal Time.) Local Sidereal Time is identical with the H.A. of Aries, and if we subtract the R.A. of the star from this, we obtain its H.A.

CALCULATION OF HOUR ANGLE OF PROCYON

TO FIND:	H.A. of Procyon (α Canis Minoris).		
PLACE:	New York (Longitude 74° West).		
TIME:	9 March 1954, 21.30 hrs. Local Zone Time.		
		<i>hrs.</i>	<i>mins.</i>
Zone Time:		21	30.0
Zone Difference:		5	00.0
		26	30.0
	minus	24	0.00
Greenwich Mean Time:		2	30.0
		<i>hrs.</i>	<i>mins.</i>
Time Interval since noon:		14	30.0
Correction for Sidereal Time:			2.5
Sidereal Time interval since noon:		14	32.5
Sidereal Time at noon (from tables):		23	06.7
		37	39.2
	minus	24	00.0
Greenwich Sidereal Time:		13	39.2
Longitude West 74° :	minus	4	56.0
Sidereal Time at New York:		8	43.2
Rectascension of Procyon:		7	38.0
Hour angle of Procyon:		1	05.2

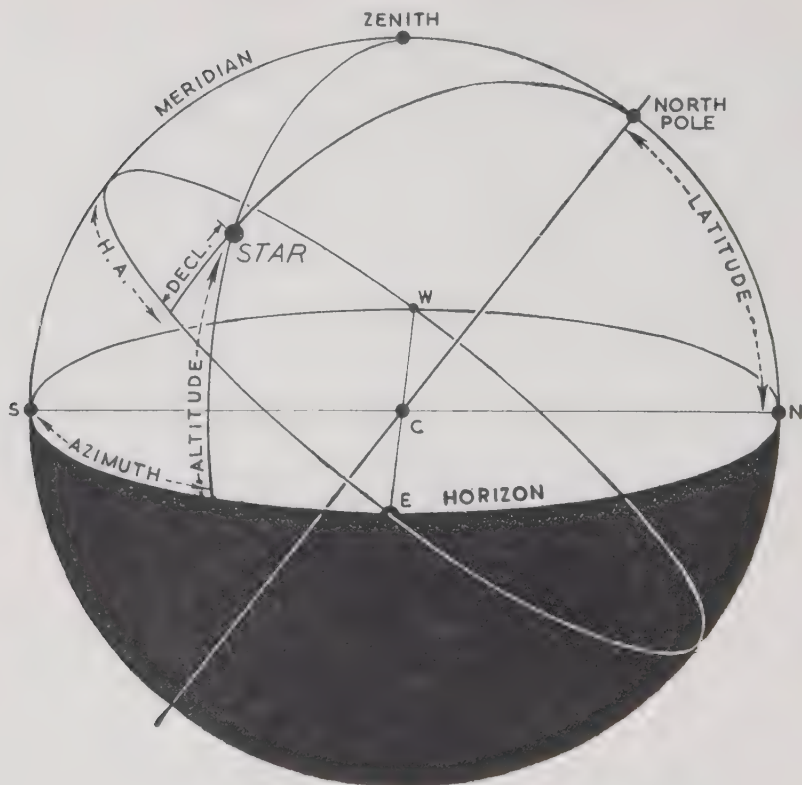


Fig. 14. Measurements on the celestial sphere

In our example this is 1 hour 5.2 minutes, which also is the Sidereal Time interval since the meridian passage of the star. Usually we are interested in the H.A., but if we want to know the time interval, expressed in Mean Time, we have to convert this. For this purpose we reverse our previous procedure, and subtract ten seconds for every hour and one second for every six minutes, expressing these as a decimal fraction of minutes before doing the subtraction. In our example we find that the Mean Time interval since Procyon's meridian passage was 1 hour and 5 minutes.

The H.A. of the star, could, of course, be converted into degrees (the result in our case would be $16^{\circ} 18'$) and this represents the angle which the meridian makes with Procyon's hour circle at the Pole.

Now we have all the necessary details which govern the relationship

between the celestial and the terrestrial systems of reference. Our latitude determines the tilt of the celestial axis with reference to our horizon, and this, in turn, fixes the altitude of the pole and the equator. Time and longitude together with the season determine the position of the celestial sphere with reference to the meridian, and govern the Sidereal Time and the hour angles of the stars and of Aries.

There is one more conclusion, however, which we can draw from our diagram: the position of the observer on Earth finds its counterpart on the celestial sphere in the zenith, and for all our calculations and diagrams we need consider this one sphere only. We can quite neglect the fact that the Earth should be represented by a minute speck in the centre of the celestial sphere, which is a simplification that will prove extremely helpful later on.

7

The Path of the Sun

IT IS one of the elementary facts which we learnt as children that the Sun rises in the East, attains his greatest altitude in the South, and finally sets in the West. But this is—strictly speaking—true on only two days of the year, on 21 March and on 23 September. On all other dates the Sun does not rise due East nor does he set due West. On the two days mentioned, however, the Sun is exactly on the celestial Equator, which cuts the horizon in the East- and West-Points.

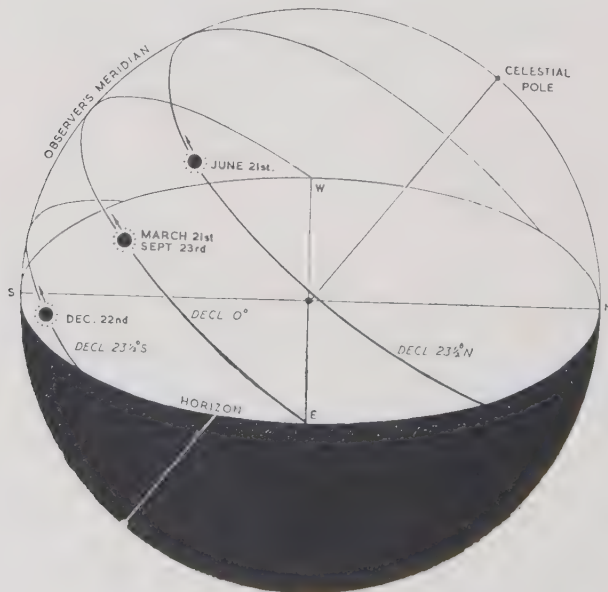


Fig. 15. The daily path of the Sun

As the ecliptic, along which the Sun travels in the course of the year, is inclined to the equator, the Sun's declination alters and he may be either South or North of the equator. In the latter case, considerably more than half of the daily circle described by the Sun in the sky is above the horizon, and as the Sun takes 24 hours to complete the circle, we have more than 12 hours of daylight. The point of sunrise is then more towards the North-east, and that of sunset towards North-west. These are the conditions during the summer.

In the winter, the position is reversed. The Sun's declination is then south, and we have less than 12 hours of daylight, and the points of sunrise and sunset are more towards the South.

The Sun's movement along the ecliptic is reckoned from the point where the R.A. is 0 hrs. The declination of the Sun at that point is 0° , and this position he occupies once every year on 21 March. From that date onwards, his R.A. increases by about 4 minutes per day, and the declination also increases, towards North. The highest point, $23\frac{1}{2}^\circ$ North of the Equator, is reached on 21 June, and then the Sun descends again, crossing the equator for the second time on 23 September, reaching $23\frac{1}{2}^\circ$ South on 22 December, and returning to the equator again on 21 March.

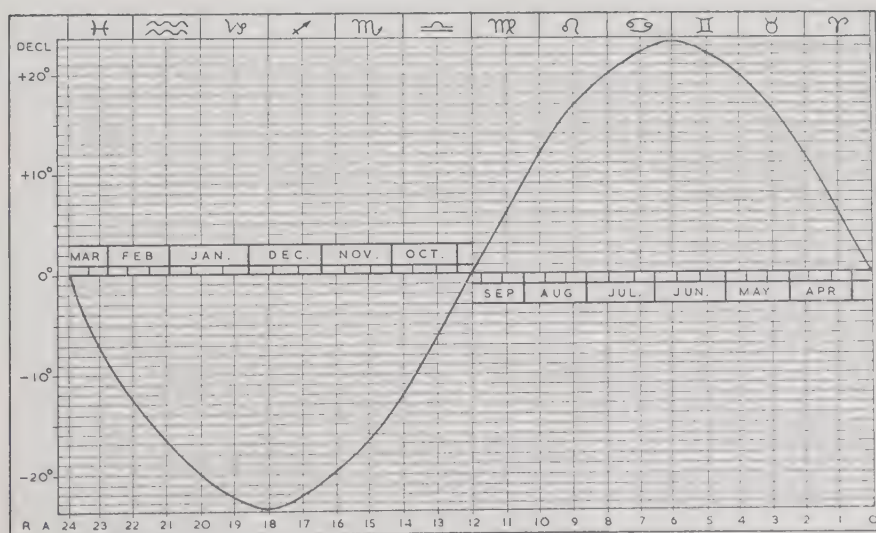


Fig. 16. Co-ordinates of the ecliptic

As the Sun is the only heavenly body visible during the daytime, his changes in declination are of great importance to navigators, and tables of the Sun's declination throughout the year, worked out to a high degree of accuracy, occupy a considerable number of pages in all Nautical Tables.

OUR QUADRANT

Early navigators never had difficulties with finding their latitude, but, as we have already seen, the determination of longitude depends on a comparison of Local Time with Greenwich Mean Time, and without accurate clocks or watches there is no means of comparing these.

In order to find one's latitude, it is necessary to measure the altitude above the horizon either of the Sun or of a star, and as measurements of altitude are constantly required for the solution of problems of navigation and for a number of other astronomical calculations, it is best to equip ourselves with an instrument which enables us to make such measurements.

The old mariners were quite happy to find their latitude with an error of 10 or even 20 miles, and with some care we should be able to determine it even more accurately with the aid of the simple instrument which we are going to construct now.

All we need is a piece of wood, preferably planed and sandpapered, measuring 12" by 12", and about 1" thick. Plywood is best for this purpose, but anything else which may be at hand will serve the purpose. One of the sides should be perfectly straight, and, parallel to it, at a distance of about one inch, we draw a line on the board. Along one of the other sides, also one inch away from it, we draw a second straight line, which must be accurately perpendicular to the first. With a pair of compasses we then describe a circle around the point of intersection of these two lines, the radius of which must be exactly 10 inches.

Next, we copy the two sections of the scale from the end of this book, and draw them on good drawing paper. These are then cut out and glued on to the board, so as to make the outer circle on the two sections coincide with the quarter-circle which we have drawn on the board.

The two sections should fit exactly at the 45° divisions, and 90° should be exactly over the first of our two straight lines, and 0° over the second.

At the point where these two lines intersect, we drive a pin into the wood, and tie a thread to it which has a small plumb-bob at the other end.

Finally we have to fit two peep-sights. These are made from strips of thin sheet metal; one of them has a hole about $\frac{1}{8}$ inch diameter drilled in its centre, and the hole in the other is about half that size. These are fitted to the board so as to make the centres of these holes at exactly equal distances from our first pencil-line on the board.

As it is difficult to see the stars, especially the fainter ones, through these holes, we file V-shaped notches in each of the two vanes, again so that their centre lines are at the same distance from the pencil line.

When using this quadrant, a 'sight' is taken while the plumb-line is allowed to hang freely. When it has stopped swinging, the thread is pressed against the board with the thumb, and the quadrant can then be taken down to read off the altitude of the star which has been observed.

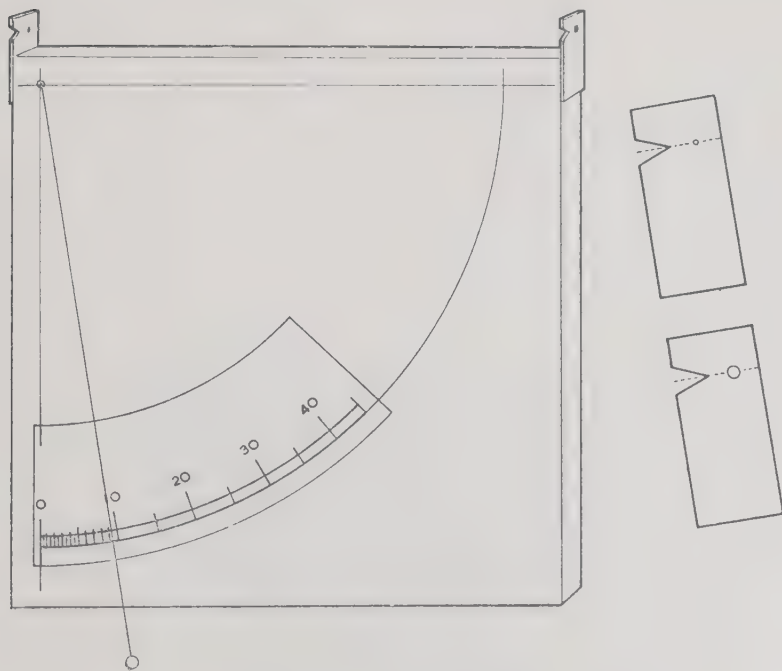


Fig. 17. Our quadrant

Our quadrant is accurate enough to enable us to find our latitude exact within about 10 miles either way. If we observe the Sun's altitude at noon on 22 April, we may find it to be 50.8° . The table at the end of the book gives us the Sun's declination on that day as 12.1° , and from these two figures we can calculate our latitude by writing down a simple sum:

Observed Altitude of Sun:	50.8°
Subtract this from 90°	$\underline{90.0^\circ}$
Zenith Distance:	39.2°
Decl. of the Sun:	plus $\underline{12.1^\circ}$
Latitude:	$\underline{51.3^\circ}$

If the observations with our quadrant are made carefully, they can be expected to be accurate within one-tenth of a degree, and as each degree of latitude equals 60 nautical miles, our measurements should not be more than 6 miles in error, even though we have neglected the corrections which navigators apply to their observations in order to obtain the greatest possible accuracy.

8

Time

TIME SEEMS to be such a simple arrangement, but it is surprising how complicated it really is. Already we have defined Sidereal Time, and have found that it differs appreciably from the time reckoning which we use for our everyday purposes. But our Civil Time is not identical with the time indicated by the Sun either, although it is based on the daily rising and setting of the Sun, which provides the fundamental time scale which governs all our activities.

On this journey along the ecliptic, the Sun does not proceed at a uniform speed, but travels faster during the winter, and more slowly during the summer.

This strange behaviour is caused by the Earth's movement along her elliptical orbit. When the Earth is near the Sun, as she is in the winter, she travels faster, and during the summer, when the distance is greater, her speed is less. This irregularity makes the Sun lose or gain a little every day as compared with a clock which goes at a uniform rate.

Another cause for the Sun's irregularities is the actual movement along the ecliptic, which introduces further errors into the rate at which the Sun loses as compared with Sidereal Time. During June and December, when the Sun is in the highest or lowest part of the ecliptic, he has to travel only about 27 degrees along the ecliptic in order to effect a change in R.A. amounting to 2 hours. In March and September, however, the Sun has to travel about 33 degrees to make a similar progress with respect to the divisions of the celestial equator.

To overcome all the complications introduced by these irregularities, it has been agreed to regulate our clocks not by the true Sun, but by the Mean Sun, an entirely fictitious body, which travels along the celestial equator at a uniform speed, and not, like the true Sun, along the ecliptic at a non-uniform speed.

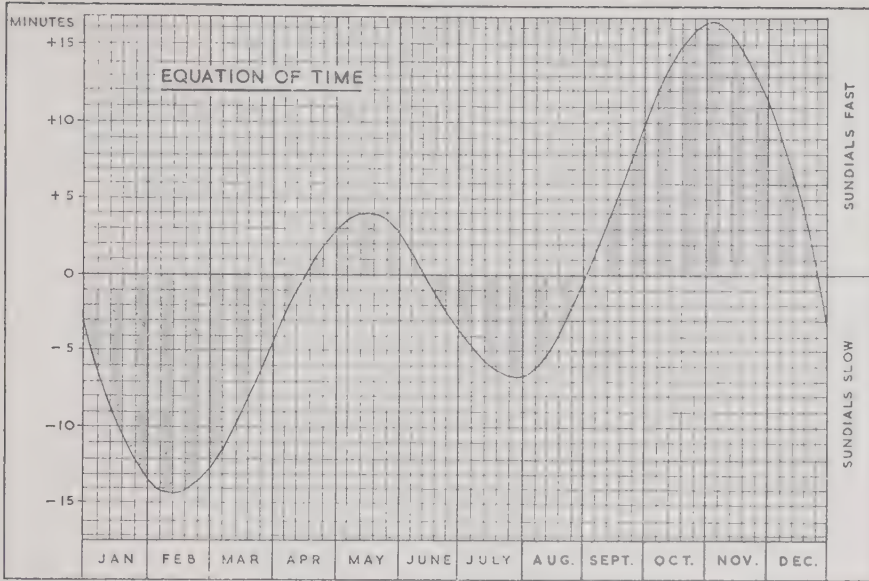


Fig. 19. The equation of time

The difference between Mean Time and Apparent Solar Time (as the time indicated by the Sun is called), is the Equation of Time. At its maximum, early in November, all sundials are about 16 minutes fast compared with Mean Time, and at its minimum, about the middle of February, they are 14 minutes slow.

With these considerations, we are now able to fix, not only our latitude, but also our longitude, by observations of the Sun.

The Sun always culminates, that is reaches the highest point of his daily path, when it is 12 noon by Apparent Time; the Sun is then due South, and to find our longitude in terms of hours and minutes, we only have to note the Greenwich Mean Time of the Solar Noon, and apply to it the Equation of Time. The result is our longitude, which we then have to convert into the more conventional degrees.

OUR POSITION ON EARTH

Let us assume we observe on 15 May. We have to estimate the time of Solar Noon, and some time before this we start measuring the Sun's altitude at intervals of about 20 seconds, noting the G.M.T. of each

observation. This we continue until we notice that the Sun begins to descend, that is, the time of Solar Noon has passed.

The Sun's meridian passage, and the instant of his greatest altitude was observed at 11 hrs. 54.3 minutes, and the observed altitude was 57.5° . Two simple calculations give us our position from these figures:

	<i>hrs.</i>	<i>mins.</i>
Time of Observation (G.M.T.)	11	54.3
Equation of Time		3.7
Apparent Solar Time at Greenwich:	11	58.0
Local Solar Time	12	00.0
Time Difference:	0	2.0

The last figure, 2.0 minutes, is converted into degrees at 4 minutes = 1° and, as Greenwich Time is least, the Longitude is East.

The latitude is calculated as before:

Observed Altitude:	57.5°
Subtract from 90°	
Zenith Distance	32.5°
Sun's Declination:	18.8°
Latitude:	51.3°

Thus, a single observation of the Sun has given us our position on Earth, which, in this case, was a little North-west of Maidstone in Kent.

SUNDIALS

The ever-changing declination of the Sun makes it almost impossible to estimate the time of the day by the position of the Sun with any degree of accuracy. Early man probably made the first attempts at finding the time by putting a stick in the ground, and dividing a circle around it into equal divisions. The shadow cast by the stick then gave a rough measure of time. But a careful observer would soon have noticed that the time interval between the passage of the shadow over two of the divisions of the circle altered appreciably with the seasons.

But already more than three thousand years ago it was discovered that the shadow cast by a stick which is inclined to the surface of the Earth at an angle which makes it parallel to the Earth's axis, will mark off equal intervals of time, whatever the Sun's declination might be. And that, in short, is the whole secret of making sundials.

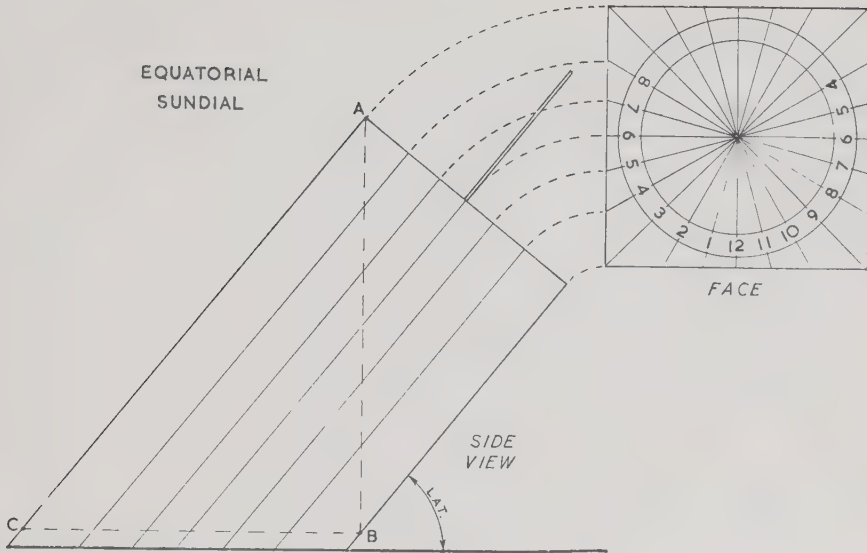


Fig. 20. Equatorial sundial

Of course, there remains the problem of finding the divisions on the dial which mark off the hours, but this is easily solved. Supposing we had a stick or a wire which is exactly parallel to the axis of the Earth, with a dial mounted around it which makes a right angle with the wire, then this dial would be in the same plane as the celestial equator, and, owing to the uniform rotation of the Earth, the shadow cast by the wire would cover equal angles in equal time intervals.

A dial of this kind is called, for obvious reasons, an *equatorial dial*. It has, however, one disadvantage. Being in the plane of the equator, it is of use only while the Sun is above the equator, that is, during the summer. For the remainder of the year it is useless, as the wire casts no shadow on the dial.

Let us suppose that our equatorial dial is on the end of a square piece of wood, inclined at an angle equal to our latitude. We could then mark the hour divisions along the sides of this piece of wood, from the points where the lines on the dial meet the edge. Then we cut the wood along the line *B-C* (see Fig. 20), and here we obtain a horizontal face, and from the points along its edges where the lines on the sides of the wood meet them, we can construct the hour-lines of a *horizontal dial* by connecting them with the centre of the dial. The shadow-casting

latitude, and from the point E we draw a line which meets $O-F$ at a right angle in F . The distance $E-F$ is then marked off on $A-B$, starting from the point E , and we thus obtain G . In this point we construct angles of 15° each on either side of $A-B$, until these lines no longer meet the sides of our dial. Then two lines are drawn from G through the two corners of the dial, meeting the 6 o'clock line in I and H , and in these two points we again construct angles of 15° each.

These angles divide the edges of our dial, and if we connect the point O with these divisions, we obtain the hour-divisions of the sundial. The actual size of our construction is quite unimportant, and so is the shape of the face. For a given latitude, the angles subtended by the hour-divisions at the point O are always the same, and once they have been found, they can be used in the construction of a variety of sundials.

Let us imagine the triangle $O-E-F$ were folded up until it is at right angles to the paper, standing on the side $O-E$; then $O-F$ represents the Earth's axis, around which the Sun moves at a uniform speed. If $E-G$ is then folded so that G comes to rest on F , we can easily see why the uniform divisions of 15° each project into the unequal divisions marking the hours on the face of our dial.

If we had cut the block of wood in Fig. 20 along the line $A-B$, we would have obtained a *vertical dial*, such as are found on walls which face exactly south.

The construction of such a dial is similar to the one just described,

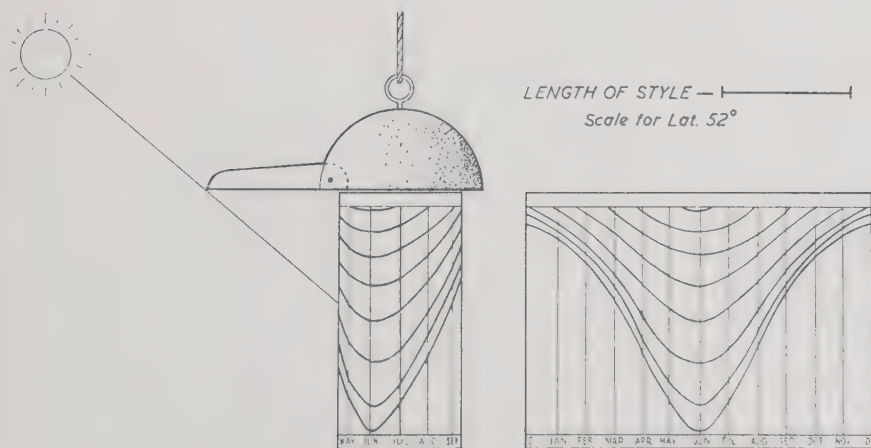


Fig. 22. Cylinder dial

only the diagram has to be turned upside down, and the height of the style, that is the angle $E-O-F$ is not made equal to the latitude, but equal to 90° minus the latitude.

Pocket-dials were very much in use at one time, and these usually indicated the time by the altitude of the Sun alone, disregarding his azimuth. Fig. 22 shows one type of these dials, which is a *cylinder dial* with a rotating head by means of which the style can be set over the date, and the length of the shadow then indicates the time. The style can usually be folded flat against the cylindrical part, to make sure it is not broken off when the dial is put in the pocket.

Another type is shown in Fig. 23. Here, the shadow of a little pin falls across the dial, and the time can be read off along the line which is nearest to the current date. This type of dial was in use at Caesar's time already, and these are called *disk dials*.

The construction of these types is obvious, the only difficulty being the calculation of the Sun's altitude at different hours of the day and times of the year. But this is a problem which we shall solve in the next chapter.

The lines on these two dials, which are marked with the names of the months only, should actually give a date as well. As drawn in these two diagrams, they are for the 21st of each month, and the times at intermediate dates must be estimated.

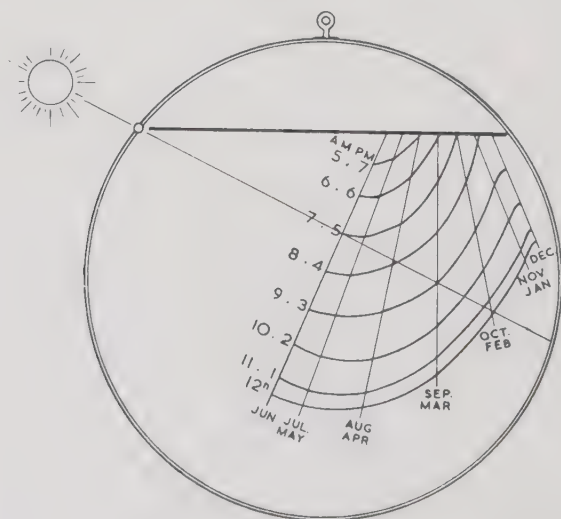


Fig. 23. Disk dial

9

Solving Problems

THE TIMES of sunrise and sunset, the length of daylight, the duration of twilight, direction finding by the stars, navigation and the determination of time are all problems of mathematical astronomy, involving a considerable amount of calculations if great accuracy is desired. But all these problems were solved long before the astronomers of the past were equipped with the mathematical knowledge necessary for such calculations, and we shall now solve these problems as they did, without mathematics, but with an accuracy considerably greater than they were able to obtain.

All these problems are based on the position in the sky of one or the other of the heavenly bodies, and, as we have seen already, this position depends on certain relationships between the two systems of co-ordinates which we use. In every problem we find the same five quantities :

1. Altitude of Sun or Star
2. Azimuth of Sun or Star
3. Hour Angle of Sun or Star
4. Declination of Sun or Star
5. Latitude of Observer

and, as we shall see presently, only three of these need be known to enable us to find the other two.

The obvious way of attempting the solution of any problem, astronomical or other, is, of course, that of constructing a model, and studying this. This is precisely what early astronomers did when they constructed celestial globes, and navigators as late as the early nineteenth century used these for the solution of many of their astronomical problems.

The construction of such an instrument need not be as elaborate as that of the medieval globe shown on the frontispiece of this book; in fact, the fewer the ornaments, the better it will serve its purpose.

A black rubber ball, the diameter of which is not important, will do very well for our experiments. On this ball we mark the two poles of the celestial sphere, some of the R.A. lines connecting the poles, and the celestial equator. With some care it should be possible to draw the ecliptic as well, especially if the measurements given in Fig. 16 are used in plotting it.

Next we cut a ring from fairly thick cardboard, the inner diameter of which should be only a little larger than that of our ball. This ring is graduated in degrees, two points, diametrically opposite, are marked 90° , and on each side of these divisions down to 0° are added. Thus, we have divided the circle into four quadrants of 90° each.

At the points marked 90° , we push a pin through the width of the ring, and when it begins to protrude at the inner side, we place a small washer over it and bring our ball into position, so that the pin, if pushed in a little farther, enters the ball at the pole. With both pins in place, it should then be possible to spin the ball around without it touching the ring.

Finally we cut a circular hole in the top of a box, again just a little larger than our ball, and at two opposite points we cut slots into which the meridian circle of our globe is set. The ball must be placed in this hole in such a manner that exactly half of it is above the top of the box, and the other half inside it. The edge of the circular hole in the top of the box is marked with the cardinal points, and this completes our celestial globe.

For the solution of astronomical problems with the aid of our globe we need one more piece of equipment, however. This is a quarter-circle, cut from cardboard, which is of exactly the same diameter as the meridian circle of the globe, and this is graduated in degrees from 0° to 90° . The 0° division of this quarter-circle is set on the horizon of the globe, and the other end touches the meridian circle in its highest point. This quarter-circle is then at right angles to the horizon, and the altitude of any point on the globe can be measured, representing the altitude above the horizon of a celestial body.

In illustration of the method of use, let us work out an example with our globe. On a day when the Sun's declination is 20° North, find the times of sunrise and sunset, and also find the instant when the Sun's altitude above the horizon is 40° .

A pencil, or a piece of chalk, or whatever will make a mark on the

surface of our globe, is held against the 20° mark on the meridian, and the globe is set spinning. The chalk will trace out a circle on the globe, which represents the Sun's path of the day. Somewhere on this circle we make a mark, which represents the actual position of the Sun, and the globe is then tilted, together with the meridian circle, so that the pole is exactly 51° above the horizon, which is the latitude for which these calculations are to be made. This operation is called *setting the globe*. Then we turn the globe about its axis, until the mark representing the Sun is exactly on the horizon. In this position we hold the

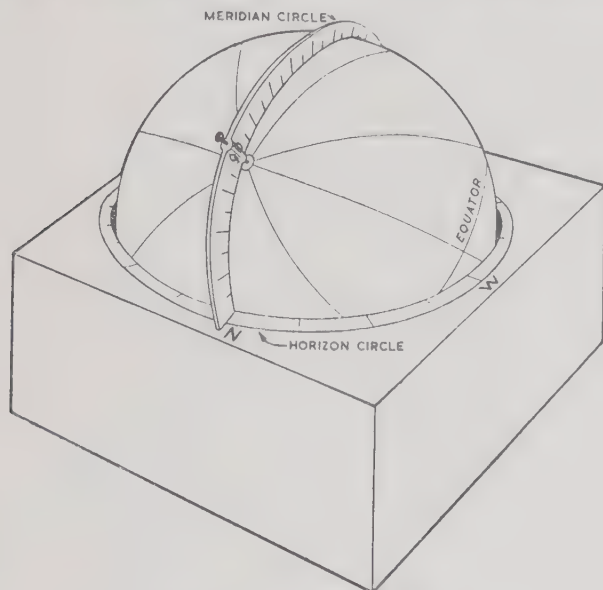


Fig. 24. Celestial globe

globe steady, and draw a line from the pole along the meridian circle. Then we turn the globe until the Sun is exactly under the meridian, and measure the angle which the line which we have just drawn, makes with the meridian. This angle, converted into time, will be 7 hours, 40 minutes. Sunset on that day is, therefore, at 7.40 P.M., and sunrise at 12 minus 7.40, that is 4.20 A.M. Both these times are Apparent Solar Time, and to find the times of sunrise and sunset as determined by G.M.T., we have to apply the Equation of Time and make also a correction for our longitude.

For the other problem we need the quarter-circle and to hold this in such a position that the 90° mark touches the highest point of the

meridian circle, which is the 39° division if the globe is set for a latitude of 51° . Around this point the quarter-circle is considered to be hinged, sweeping out different points of the compass on the horizon circle. By turning the globe and adjusting the quarter-circle, it is possible to find a position in which the Sun is exactly under the 40° division, and we can again measure the Sun's hour angle. The azimuth at the same time is indicated by the point on the horizon circle on which the quarter-circle rests. The time will be found to be 3 hrs., 20 min., which can be either before noon or after noon, and the actual time is either 8.40 A.M. or 3.20 P.M. The azimuth of the Sun at that time is 70° from South, towards the East if the time is A.M., and towards the West if it is P.M.

Some experiments with this globe will soon convince us that, as was said already, we only need three of our five quantities in order to find the remaining two. No other astronomical gadget gives a clearer picture of the problems than does the globe, and in order to understand the pages which are to follow, an hour's experimenting with this little instrument is time well spent indeed.

The globe, however, has two disadvantages: unless it has a diameter of several feet, the accuracy of the results leaves much to be desired, and even quite a small one is still rather a bulky piece of equipment.

It is comparatively easy to construct map-projections which have certain properties, and they seem to be the answer to our problem. Just as navigators use maps and charts of the Earth's surface on which they make their geometrical constructions, without having a terrestrial globe with them all the time, so might we try to find a map-projection which is easy to construct, and at the same time suited to the kind of problems we have to solve.

The different projections of the Earth's surface which we can find in any atlas, all have their special purposes. Some of them reproduce equal areas on the Earth by equal areas on the map, but distorting the angles. Others have all the meridians parallel to each other, and therefore the parts near the equator are represented on a much smaller scale than are those at the poles.

For our purposes it seems best to have a projection which preserves the angles on our celestial sphere, and in which all circles on the sphere are represented either by straight lines or by other circles of various radii. All other considerations, like scale of representation or true representation of areas, are of little importance to us, as all measurements on the sphere are made in degrees, and we have no irregular shapes, like the coasts of the continents, on our celestial sphere.

These conditions are fulfilled by the *stereographic projection*. In 150 B.C., the Greek astronomer Hipparchus invented the *astrolabe*, an astronomical instrument which is capable of solving all the problems which we have been considering so far, and this is based on the stereographic projection of the celestial sphere.

Astrolabes, though rather modernized, are still used today, particularly in air-navigation, and it can well be said that the astrolabe is the oldest scientific apparatus deserving of that name.

Let us now consider how we can obtain this projection of the sphere. Fig. 25 shows the celestial sphere, with the two poles and the equator. The points and circles on this sphere are to be projected on to a flat surface, and for this we choose the plane of the equator. Any point on the sphere can be connected with the point *A* by a straight line. *A* is the South Pole of the celestial sphere, and it is the projecting point of our construction. This is not the only point which can be chosen for this purpose, and in fact any point of the sphere will do but for our purpose this is the best, because we thus have the celestial North Pole in the centre of the projection, which is very convenient.

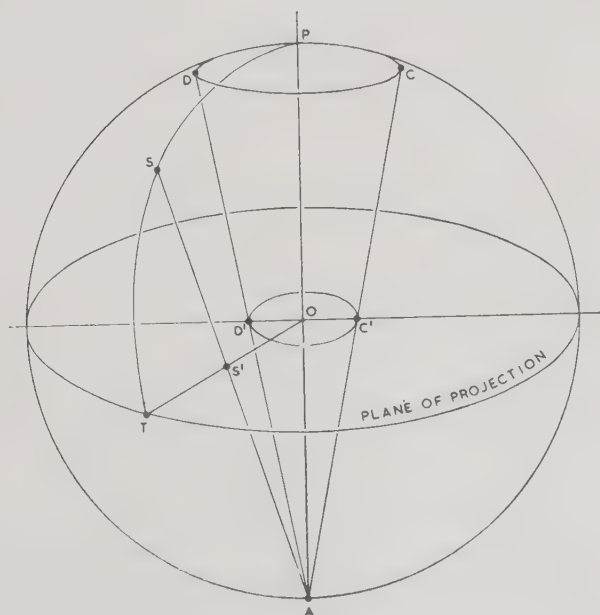


Fig. 25. The stereographic projection

The line connecting a point on the surface of the sphere with A intersects the plane of the equator somewhere, and the point of intersection is the position of the projected point. The point S thus appears as point S' in the projection.

From our diagram it now becomes obvious that the small circle $C-D$, which is actually a circle of declination, appears as the circle $C'-D'$ in the projection, and the arc $P-S-T$, representing one of the Hour Circles, appears as the straight line $O-S'-T$.

Here we can see already that all circles on the sphere appear as circles in the projection, although the diameters of these may vary greatly. Only those circles which pass through the centre of the projection, that is, P , and also through the projecting point, A , appear as straight lines. The construction of this map-projection, therefore, is fairly simple, as all we need is a ruler and a pair of compasses. There will be none of those complicated curves by which the meridians of the Earth are often represented on the maps in an atlas, and the projection of the celestial sphere, with its hour circles, declination circles, and the ecliptic, presents no great difficulties, once the principle has been understood.

The upper circle in Fig. 26 represents the sphere which we want to project on to a flat surface, and it is seen from such a position where its equator and the circles of declination are presented edgewise.

The points where the lines representing these meet the circumference of the circle are connected with the point C , and the intersections of these connecting lines with the equator mark off the lengths of the radii of the projected circles, which are then drawn underneath.

In the projection, the pole is represented by P' , surrounded by the circles of declination, and the hour lines, representing the R.A. of 0 hrs., 6 hrs., 12 hrs. and 18 hrs., intersect each other at the pole. These, of course, need not be actually constructed, but can be drawn first in order to fix the centre of the projection.

The projection of the ecliptic is not quite so straightforward. Not being represented, as are the declination circles, by a line parallel to the equator, its two ends will obviously project as points whose distances from the centre of the projection are not equal. The two points can, however, be found, and if we then find the point which is exactly half-way between the two, we can draw a circle which passes through both these points. This circle is the projected ecliptic. For all such oblique circles we have to find the projections of both ends of their diameters before we can actually draw the circle. For the ecliptic in our diagram, these are the points E and F .

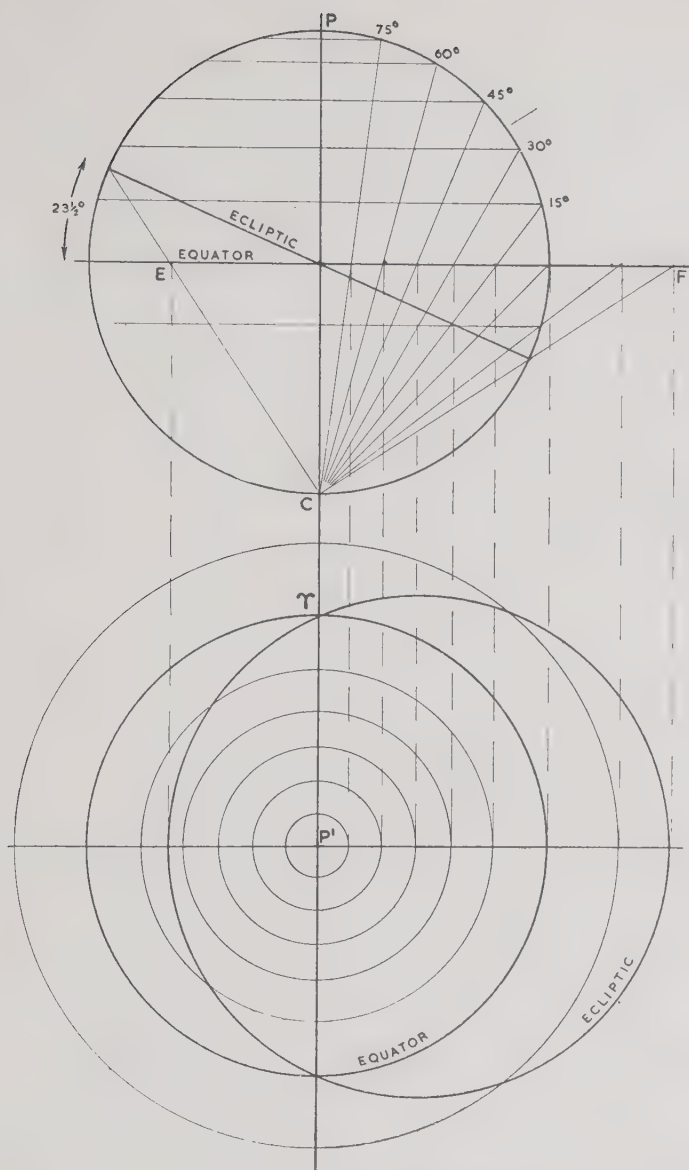


Fig. 26. Projection of the celestial sphere

In our projection we find that the uppermost part of the ecliptic, compared with the circles of declination, is at a declination of $23\frac{1}{2}^{\circ}$ N., and the lowest part of it at a declination $23\frac{1}{2}^{\circ}$ S. Furthermore, the projected ecliptic intersects the equator in exactly those points where the R.A. of 0 hrs. and 12 hrs. intersects it, and it thus represents accurately all the features of the ecliptic circle on the celestial sphere.

One of the points of intersection is marked with the sign of Aries in the diagram, and R.A. is reckoned anti-clockwise from this point.

We thus have a skeleton of a star map, and the individual stars can be marked on it, each at its proper R.A. and decl., but, as this projection shows the celestial sphere as it would be seen from the outside, like a celestial globe, all constellations have left and right reversed. Most of the old star maps are drawn in this fashion, and celestial globes always show the constellation reversed, as is shown on our frontispiece.

The star map at the end of the book, however, has been drawn to show the constellations as we see them from the inside of the celestial sphere, although it, too, is based on the stereographic projection. For this reason the hours of R.A. on our map are marked along the edge in a clockwise direction, and the cardinal points marked on the mask which goes with it represent the true state of affairs only when the map is held overhead.

For the purpose of solving actual problems, however, it is not enough to have a projection of the celestial sphere only; we also have to construct a projection of the horizon with circles of altitude (these are called *almucantars*) and circles of azimuths. These are a little more difficult to find, but the principle of constructing them is still the same.

Again, we first draw our celestial sphere with the two poles and the equator (*see* Fig. 27). Our horizon, represented by the line $H-H$, is inclined to the equator so as to make the altitude of the pole, measured along the meridian, equal to the latitude from which we make our observations. A line at right angles to the horizon, erected in the centre of the circle, meets its circumference in the zenith, Z .

By projecting the two ends of the horizon from the point C on to the equator, we obtain the ends of the diameter of the projected horizon, which are the two points marked H' . The zenith projects as Z' , and it will be noticed that it is not the centre of the projected horizon. The actual centre of that circle is C' , and this has to be found by trial and error, as only the two end-points of the diameter of that circle can be found.

It becomes now evident that the stereographic scale expands rather rapidly at distances beyond the equator, but the projection still remains

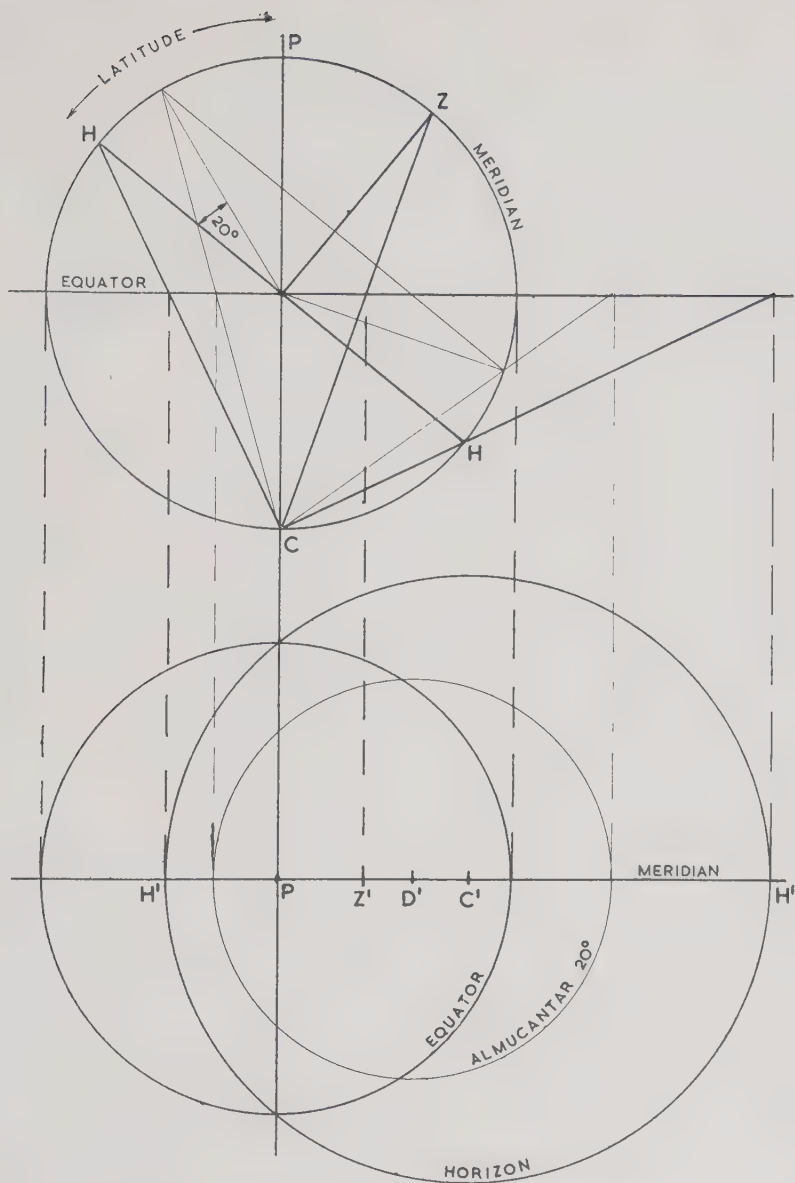


Fig. 27. Projection of the horizon and almucantars

correct, as we notice again here, where the horizon, as it should, passes through the two points of the equator which are due east and due west.

If we imagine a circle around the sky, which is everywhere exactly 20° above the horizon, we could draw this as a straight line, parallel to the horizon in the upper circle of Fig. 27. This line then represents the almucantar of 20° . As with the horizon, we can project this circle by finding the ends of its diameter, and then, by trial and error, find its centre D' in the projection, and finally draw it. Further almucantars can be added in a similar manner, covering the whole of the space between the horizon and the zenith at intervals which are small enough to read the altitudes between the almucantars with the required accuracy. A circle of 12 inches diameter can easily be divided into single degrees, and we thus obtain an accuracy which is offered only by a fairly large globe, evidence of the advantages of the stereographic projection.

Finally we have to consider the construction of the azimuth circles, which are perpendicular to the Horizon and which all meet in the zenith. When making such a projection, they should be drawn together with the almucantars in the same projection, while we shall here keep the two on separate diagrams for the sake of clarity.

Three of the azimuth circles are denoted by the letters A , B , and C in the celestial sphere of Fig. 28. However much we study this figure, there seems to be no direct way of projecting these, and we have to resort to a sort of a trick. Only one of the azimuth circles can be projected directly, and that is the circle which is at right angles to the plane of the paper, passing from Z over O to X . This is the circle which connects all those points in the sky which, though at different altitudes, are all either due east or due west. The ends of the diameter of this circle project as points Z' and X' , and the centre of the circle, exactly half-way between the two, is the point D . Around this centre we draw the circle which passes through Z' , and it is sufficient to draw only that part of it which lies inside the circle representing the horizon. As we already expected, it meets the horizon exactly in the two points where it is intersected by the equator, which are the East- and West-points. The other two cardinal points, North and South, are indicated already by the intersections of the meridian with the horizon.

All the azimuth circles on the celestial sphere pass through the two points Z and X , and the projections of these circles must, therefore, pass through Z' and X' in the projection. Their centres, for this reason, must all lie on the line which is at right angles to the meridian,

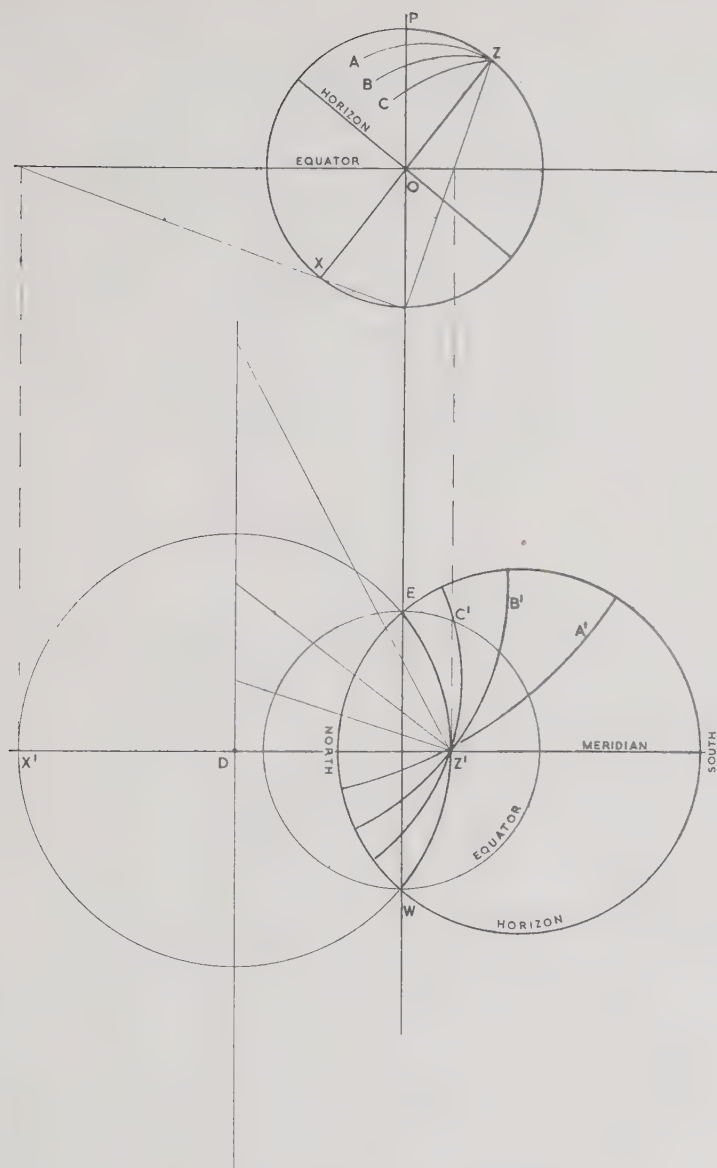


Fig. 28. Projection of the azimuths

erected in the point D , but the diameters of these projected circles will all be different. If we want to draw the azimuths for every 10 degrees, the projected circles must make angles of 10 degrees with each other at their two points of intersection, X' and Z' . As every radius of a circle is always at right angles to the circumference, the radii of the required circles, meeting in these points, must also make angles of 10 degrees with each other.

Now we can draw lines, either from X' or from Z' , making angles of 10, 20, 30, etc., degrees with the meridian, and these lines are the radii of the required azimuth circles, and they cut the perpendicular line through D in the points which are the centres of the required circles. Around these centres we draw those parts of the circles which come within the horizon, the radii being such as to make them pass through Z' exactly.

MAKING AN ASTROLABE

We are able to construct an astrolabe, which is a really versatile piece of equipment, and as, with its aid, it is possible to solve a great number of problems, it is really worth while making one.

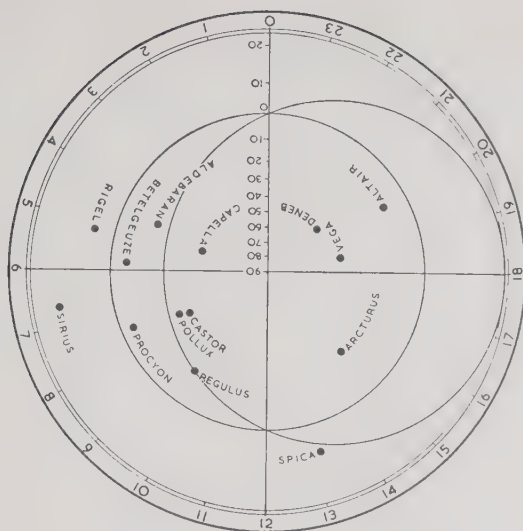
First, we have to make a projection of the celestial sphere, showing the equator, the ecliptic, and the positions of the principal stars. The edge of this projection is graduated in hours, starting from the First Point of Aries, and continuing anti-clockwise. It is not necessary to draw the lines of R.A. or the circles of decl., but a scale of the latter can be marked along one of the hour-lines as shown in Fig. 29.

In mediæval astrolabes, this part was called the *rete*, and usually consisted of an intricate fretwork disk, made from brass. We had better draw this on some transparent material like kodatrace, or scratch it on a sheet of celluloid or perspex, rubbing some Indian ink into the scratches to make them visible.

The *tablet* of the astrolabe, with the projection of the horizon, the almucantars and the azimuths, is drawn on a sheet of white cardboard or stout paper, and this is glued to a board. The tablet must be constructed for the latitude from which we make our observations, and along its edge we mark the 24 hours of the day.

The celestial equator, which appears on both projections, must be of exactly the same diameter on the tablet as it is on the rete, otherwise the instrument does not function properly.

Finally we cut a strip of celluloid, and mark a line along its centre. Somewhere on this line, towards one end of the strip, we drive a small



ASTROLABE

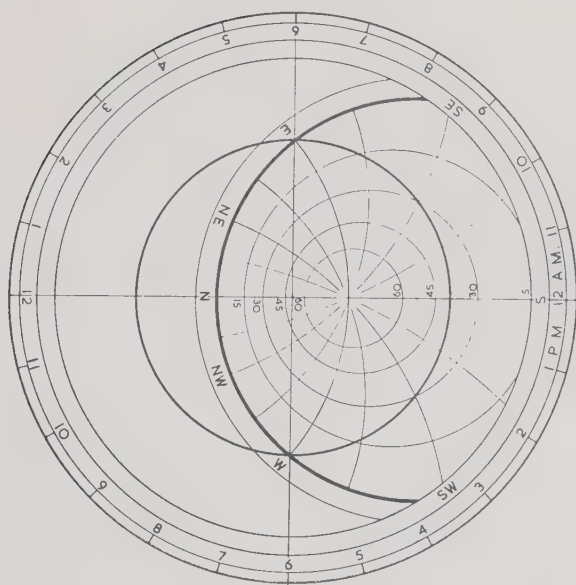


Fig. 29. Rete and tablet of the astrolabe

nail through the material, and then pass it through the centre of the rete, finally nailing it into the bottom board, so that tablet and rete are truly concentric. (*See Plate V.*)

The problems which can be solved with the astrolabe are various indeed, and we will now consider a few of them.

What is the aspect of the sky on 12 February at 8 p.m.?

First of all we have to calculate the Sidereal Time and once we have found this, we can rotate the rete until the Sidereal Time indicated on its edge is exactly on the meridian which is marked on the tablet underneath. Then we turn the marker to 8 P.M. on the outer scale of hours on the tablet, and the point of intersection of the line along this marker and the ecliptic indicates the position of the Sun in the sky. At this time, as we can see, he is well below the horizon, and it is therefore completely dark. The stars which are now situated within the horizon circle are actually visible in the sky, and we notice that Orion is due south, Capella almost overhead, and in the East the Lion is just above the horizon. The Great Square of Pegasus is just about to set in the West, and the Great Bear is in the North-east, with the handle of the Plough pointing at the horizon.

On a cloudy day we just catch a glimpse of a very bright star, well up in the sky, and due West. The date is 2 November, and the time is 7 p.m. Which star have we observed?

We set the astrolabe in the same manner as before, and note which stars are in the West. The only really bright star is Vega in the Lyre, and this was the one which we have seen.

When does the Sun rise on 1 November?

First we turn the rete until the Sidereal Time at noon is indicated by the meridian on the scale of the rete. Then the marker is also set over the meridian, and the intersection of the line along its centre with the ecliptic is the position of the Sun amongst the stars on that day. The rete and the marker are then turned together, until the Sun's position is exactly over the circle which represents the horizon in its eastern half. The position of the marker on the outer scale of hours indicates the time of sunrise.

This will be found to be 7.05 A.M. Looking up the date in a calendar, we shall find that the time of sunrise is actually before 7 A.M., and this discrepancy is due to the fact that we have ignored the Equation of Time. Our astrolabe always gives us the Apparent Solar Time, and

for correct results we have to apply the Equation of Time to the Mean Time before setting our astrolabe.

The Equation of Time for the day is plus 16.4 minutes, and as the astrolabe indicates Apparent Solar Time, we have to subtract 16.4 minutes from all the times indicated in order to obtain Local Mean Time, and this, again, can be corrected for our Longitude, and our result then will be Greenwich Mean Time.

At what time does Spica attain its greatest altitude above the horizon on 1 March?

All stars reach their greatest altitude in the South, when they cross the meridian. We turn our rete until the star Spica is on the meridian line, and then turn the marker until it indicates the Sun's position among the stars on that day. On the outer circle of hours the marker then indicates the time when Spica reaches that position, which is 2.45 A.M. The actual altitude of Spica can also be read off, and this will be 28°.

On 1 April we observe Arcturus over the eastern horizon at an altitude of 30°. What is the time at the moment of observation?

First, we set rete and marker in their relative positions according to the Sidereal Time at noon, and then we turn both together, until the mark of Arcturus on the rete is on the almucantar of 30° in the eastern half of our astrolabe. (The star descends to the same altitude again several hours later, in the western half.) The marker will then indicate the time of observation, which was 9.05 P.M.

How long do twilight and dawn last?

There are three different definitions of twilight, each having its specific purpose.

Civil twilight is defined as the time interval after sunset or before sunrise during which it is still light enough to do any work which requires daylight. It ends when the centre of the Sun is 6° below the horizon.

Nautical twilight is the time which is useful to the navigator, during which the brighter stars are visible, but before the horizon disappears in the darkness of the night. Navigators measure the altitudes of stars with a sextant, and this is of use only while the horizon is visible. Nautical twilight ends when it becomes indistinct, and at that time the Sun is 12° below the horizon.

Astronomical twilight, finally, ends when the last traces of light have

disappeared from the sky, which is the case when the Sun is 18° below the horizon.

To find the times of twilight with our astrolabe, we have to add three further almucantars to our tablet, one 6° , the next 12° , and the third 18° below the horizon.

The end of civil twilight, for instance, is then found by turning the rete and indicator until the point which marks the position of the Sun in the sky is on the first of these three almucantars, that is 6° below the horizon, and the time can be read from the outer circle of hours, where the marker indicates it.

What is the Sidereal Time?

The approximate Sidereal Time can be found with the aid of our astrolabe in quite a simple manner. First we set the marker to the position of the Sun on the day in question, and then turn rete and marker together until the marker indicates the time of observation on the outer hour circle. The hour of R.A., which is then exactly on the meridian, is the Sidereal Time at the moment.

Where in the sky do we find the planets?

As the planets are constantly moving, they cannot be marked on any star map which is intended for permanent use. In a later chapter we shall see how we can calculate their R.A. and decl. for any day, or we can take these figures from *Whitaker's Almanack*. The rete is first set for the day and hour of observation, and then the marker alone is turned until it indicates the planet's R.A. on the hour circle on the rete.

For rough estimations it is sufficient to regard the intersection of the ecliptic with the line of the marker as the position of the planet, but for more exact measurements we have to take its decl. into account, by marking the actual value of this on the line on the marker. The altitude and azimuth of this point, as indicated by the astrolabe, are then the accurate co-ordinates of the planet.

There are a few points which we must bear in mind when we are using our astrolabe. The readings obtained from it are exact only if the tablet has been constructed for the latitude of the place of observation, and all times which enter into the calculations are Local Mean Time, and not Greenwich Mean Time. For observations of the Sun we have to allow for the Equation of Time on top of that.

As Local Mean Time in the western parts of England is as much as 20 minutes slow on G.M.T., it cannot, therefore, be completely ignored.

10

The Astronomical Triangle

COMPLICATED AS the astrolabe may seem, it must have been observed that the solution of the problems boils down to the construction of a simple triangle with the corners: Pole-Zenith-Star (or Sun). Like every triangle, it has three sides, and it would seem much simpler to construct just this triangle for the solution of our problems, rather than having a projection of the whole sky in front of us all the time, as is the case when we are using the astrolabe.

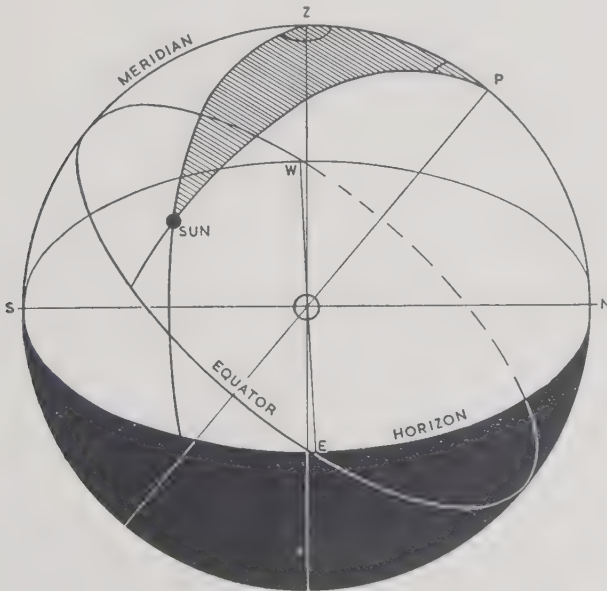


Fig. 30. The astronomical triangle

The sides of the triangle are, in one form or the other, known to us already. The distance from P to Z is, as we have seen in a previous chapter, 90° minus our latitude, and in our case we shall call it the *co-latitude*. The distance from P to S is equal to 90° minus the declination of the star or the Sun (or plus, if the decl. is south), and, for obvious reasons, we shall call it the *polar distance*. The third side, $Z-S$, is 90° minus the star's altitude, and shall be known as the *zenith distance*.

Of the three angles in this triangle, only two are of interest to us. The one at the pole is, of course, the hour angle of the star or of the Sun, and the angle at the zenith is the azimuth, reckoned from the North Point. The third angle, situated at the star, never enters into our calculations.

This triangle, naturally, is part of the surface of the celestial sphere, and in order to draw it on a flat sheet of paper, we again employ our stereographic projection. There are two ways in which we can look at our triangle for the purpose of projecting it. We can either have the pole at the centre of the circle which represents our sphere, or the zenith. In the first case, the polar distance and the meridian appear as straight lines, and the zenith distance as an arc, while in the second case meridian and zenith distance are straight lines, and the polar distance is curved.

Any problem, therefore, which entails the measuring of either zenith distance or polar distance, is best solved by a projection in which the required distance appears as a straight line. For most problems it will be found that it is best to have the zenith at the centre of the projection, and not, as with the astrolabe, the pole. Only when we want to identify a star, that is, determine its declination, will it be necessary to project the celestial sphere with its pole at the centre of the projection.

All we need for the solution of astronomical problems are a ruler, a pair of compasses, a protractor for measuring angles, and a stereographic scale for measuring the lengths of the sides of our astronomical triangle. A stereographic scale is printed in the Appendix, and should be copied carefully on a piece of good drawing paper, which is then glued on to a piece of wood, finally varnishing it, in order to make it more durable.

From this scale we can read the length of any of the sides in our triangle which projects as a straight line, and we find that a side of the spherical triangle which is 90° long should, in the projection, appear as a line 10 units long. If we use the edge of the stereographic scale for

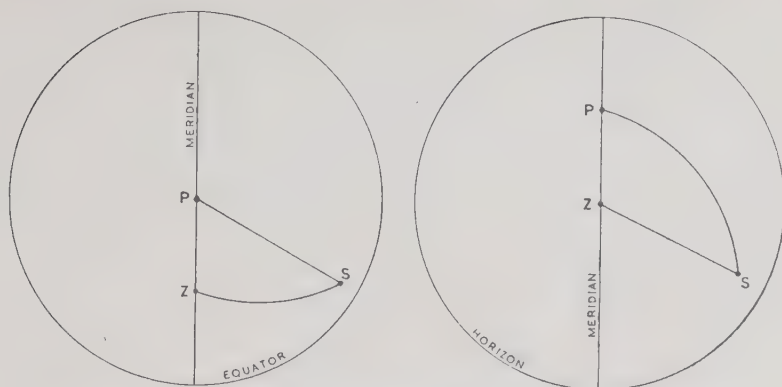


Fig. 31. Polar and zenith aspects of the astronomical triangle

our measurements, the distance, in our diagrams, from the zenith to the horizon would be about 7 inches, which is the length of our scale.

If our paper is not large enough, and accuracy is not of very great importance, the measurements can be made in centimetres, and if the greatest possible accuracy is desired the figures can be taken as inches. In this case, however, we should have a fairly large table at our disposal, and also an almost unlimited supply of paper.

The actual solution of problems with the aid of the stereographic scale is fairly simple, and in illustration of the method we shall repeat now the problem which we have solved already with the globe.

The Sun's decl. is 20° North. At what time does he reach an altitude of 40° above the horizon in a place, the latitude of which is 52° North, and what is the Sun's azimuth at the time?

First, we draw a straight line, representing our meridian, and mark Z on it, which is our zenith. We clearly mark this with a little circle around it to remind us that we have chosen it as the centre of our projection, from which we must measure all the distances. The pole, P , is 90° minus $52^\circ = 38^\circ$ North of Z , and from our scale we find that the distance for 38° should be 3.43 divisions of the scale, or inches, or centimetres. At this distance we can mark P on our diagram.

The altitude of the Sun is 40° , and from this follows a zenith distance of 50° , for which the scale gives us a length of 4.65 (in whichever units we have chosen). We can now draw a circle with the centre Z , and with a radius of 4.65 (inches), representing the almucantar for 40° altitude.

The path of the Sun on that day crosses the meridian once in the

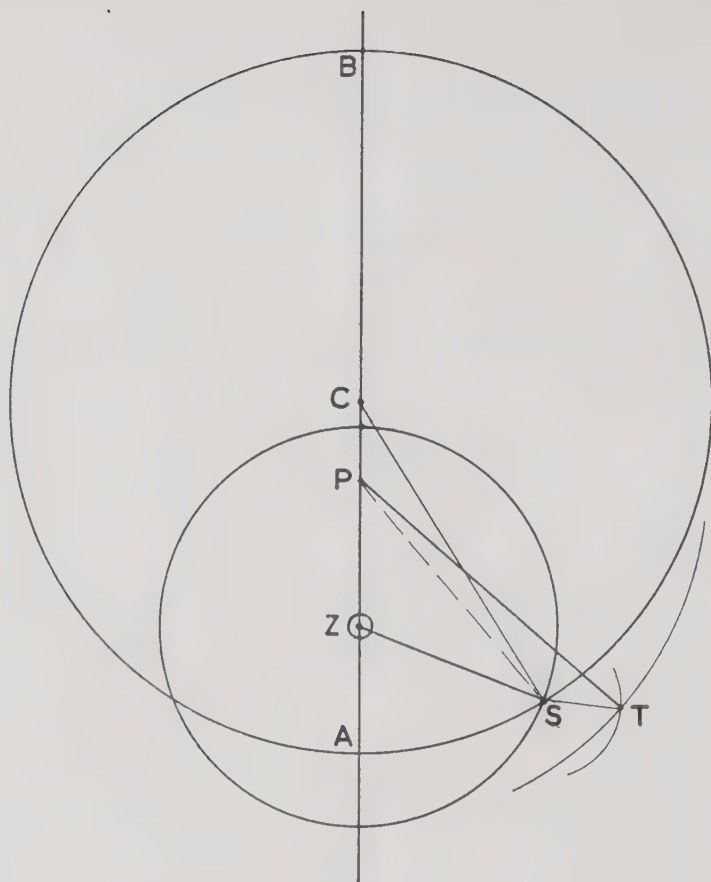


Fig. 32.

Lat. 5°	Co-Lat. C	$=$	38°	$=$	3.43
Decl. 20°	Polar dist. P	$=$	70°		
	P plus C	$=$	108°	$=$	13.8
	P minus C	$=$	32°	$=$	2.86

$2) 16.66$

	Radius	$=$	8.33
Altitude 40°	Zenith dist. $Z = 50^{\circ}$	$=$	4.65
	Azimuth: S 69° E		
	H.A.: $49^{\circ} = 3$ hrs. 16 mins.		

South, and once in the North; in the latter case, however, he is well below the horizon. These points of intersection, A and B in Fig. 32, must be calculated in terms of distance from the centre of the projection, that is from Z .

Both A and B are at a distance of 70° from P , and the distance from Z to B is therefore $P-B$ plus $Z-P$, and the distance from Z to A , similarly, is $P-A$ minus $Z-P$. For all similar constructions, therefore, we can write the little sum:

Lat. 52°	Co-Lat. C	=	38°	=	3.43
Decl. 20°	Polar dist. P	=	70°		
	P plus C	=	108°	=	13.8
	P minus C	=	32°	=	2.86
	Distance $A-B$			=	16.66
	divided by 2:				
	Radius of Sun's path			=	8.33
Altitude 40°	Zenith dist. $Z = 50^\circ$			=	4.65

Here we have all the figures necessary, including the radius of the Sun's path, and the distances from the centre of the projection of the two points through which that circle passes. We can, therefore, find the centre C of that circle, and actually draw it. The almucantar and the path of the Sun intersect at two points, and we shall consider only the easterly one. As Z is the centre of our projection, we can draw a straight line connecting Z and S , and measure the angle it makes with the meridian, which is the Sun's azimuth at the time when his altitude is 40° . This will be found to be S 69° E.

The hour angle, that is the angle at the pole, is not found quite as easily, as it is formed by the meridian and the third side of the triangle, which projects as an arc, connecting P and S . All we know about this circle is that it cuts the path of the Sun at right angles (all hour circles intersect the equator and the decl. circles at right angles, and the stereographic projection preserves these features of the celestial sphere), and that the line $C-S$ must be a tangent to that circle, touching it in S .

Supposing we had found that circle already, we could draw a similar tangent in the point P , and make its length equal to $C-S$, thus obtaining the point T , which we can then connect with S . By connecting P with S , we obtain two triangles, $P-S-T$ and $S-P-C$. These

have one side, $P-S$, in common, the sides $P-T$ and $S-C$ are equal (we have just made them thus), and the angles at P and at S , being formed by two tangents to the same circle, are also equal. The two triangles, therefore, are exactly alike, and this means that the sides $P-C$ and $S-T$ must be equal.

In order to find the tangent $P-T$, we first draw an arc with the radius $C-S$ around P , and another arc with radius $P-C$ around S . Where these two intersect, we find our point T , and by connecting it with P we can measure the angle the connecting line makes with the meridian. This angle will be found to be 49° , which, when converted into time, gives us the value of 3 hrs., 16 mins. The Sun, therefore, reaches the altitude of 40° at 8.44 A.M. (Apparent Solar Time) on that day, and his azimuth, as we have found already, is $S\ 69^\circ\ E$.

The two auxiliary circles which we needed for our construction, naturally, intersect in two points, and we must be careful when making our choice between them, remembering that the two tangents to the hour circle must intersect each other, which they would not do if we connect the wrong point with P .

Another problem, which is quite important, is the determination of the Sun's altitude and azimuth, given the latitude, declination and time.

Again, we draw the meridian, and set out Z and P , and calculate the points A and B . From these we find C , and, as it is not necessary to draw the full circle of the Sun's path, we really need determine A only, from which we can measure the distance of C from A along the meridian. (Fig. 33.)

From P we then draw a line making an angle with the meridian which is equal to the hour angle, and make its length equal to the distance $C-A$, which gives us the point T . Around this point we draw a circle with the radius $C-P$, cutting the Sun's path in S . By connecting this with Z , we can measure the angle at Z , which gives us the azimuth, and by measuring the length from Z to S with our scale, we find the zenith distance as well, and from this the altitude is determined by subtracting it from 90° .

The identification of a star entails the determination of its hour angle and declination. For this reason we must draw our projection with the pole at the centre.

Again we begin by drawing the meridian, and mark Z and P on it. Then we calculate the point A , and the centre of the circle which represents the almucantar for the given altitude, and in our example (Fig. 34) we find that Z minus C is negative; the point B , therefore,

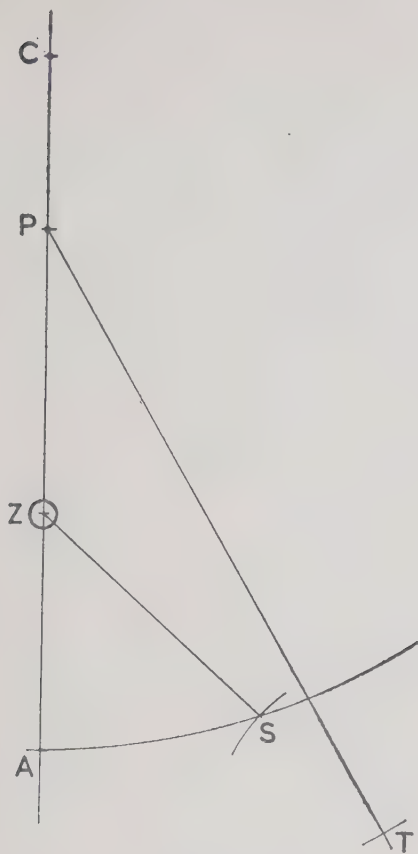


Fig. 33.

Lat. 52° Co-Lat. $C = 38^\circ$
 Decl. 20° P.D. $P = 70^\circ$
 Time 10 A.M. H.A. $= 30^\circ$ E
 P plus $C = 108^\circ = 13.8$
 P minus $C = 32^\circ = 2.86$

16.66

Radius: 8.33

Z.D. $= 39.5^\circ$ Altitude $= 50.5^\circ$
 Azimuth: S 47.5° E

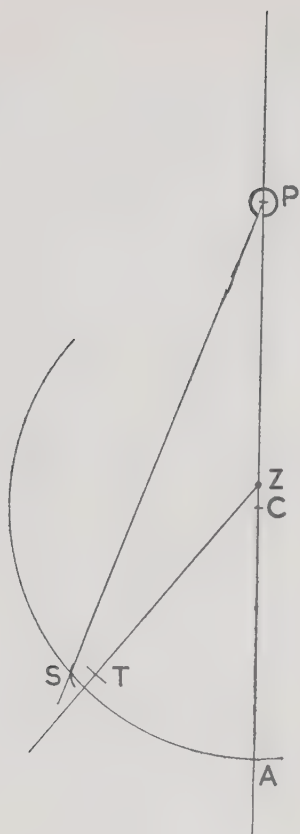


Fig. 34.

Lat. 52° Co-Lat. $C = 38^\circ$
 Altitude 60° Z.D. $Z = 30^\circ$
 Azimuth $=$ S 50° W
 Z plus $C = 68^\circ = 6.8$
 Z minus $C = -8^\circ = -0.7$

6.1

Radius: 3.05

P.D. $= 63.5^\circ$ Decl. $= 26.5^\circ$
 H.A. $= 21.5^\circ = 1$ hr. 28 mins.

lies south of P , and not, as it mostly does, north. From Z we draw a line, making an angle with the meridian equal to the given azimuth, and on it we mark the point T , the distance $Z-T$ being equal to $A-C$. Around T we draw a circle with radius $Z-C$, which cuts the almucantar in S , which is the position of the star, and by connecting it with P we can measure its polar distance, which, when subtracted from 90° , gives us the declination of the star. The angle at P is the hour angle, and by making a calculation similar to the one on page 57, we can find the star's R.A., if we remember that Local Sidereal Time minus hour angle of star = R.A. of star. We can now compare these two figures with a star map and thus find which star we have observed.

All other problems of this nature are solved in a similar manner and, just for the fun of it, the reader may attempt to find the solutions of a few more examples by himself.

What is the time and azimuth of the Sun at 9.00 A.M. this morning? (Given: latitude of observer, declination of the Sun (*see* Appendix) and hour angle.)

What is the longitude of a place where an observation of the Sun resulted in a measurement of its altitude as 40° at 11.0 A.M. on a day when the Sun's decl. was 15° North? (Given: latitude 52° , decl. 15° N., and altitude 40° .)

At what time does the Sun rise and set today, and what is the azimuth at the time? How long does civil twilight last, and how long astronomical twilight?

NAVIGATION

The problem which is of greatest importance to the navigator is that of finding the altitude and the azimuth of the Sun or a star at a given time. From these he can determine his position on the surface of the Earth, provided he has an approximate idea of his longitude and latitude.

Considering the ship's course and speed, and comparing these with the last known position of the ship, the Dead Reckoning Position is easily determined. But the effects of wind and currents, which cannot be calculated, make this only an approximation.

If a navigator observes the Sun at the time of his meridian passage, he may find its altitude to be 46° . Assuming his D.R. Position to be correct, he may find that the Sun's altitude should have been 47° , and from the difference between the observed and the calculated altitudes

he will know that his actual position is 1° North of his D.R. Position.

This principle applies to all observations, both of the Sun and of the stars, and not only at the time of their meridian passages. It is the principle of the position line. The Sun, at a certain time, is directly overhead at one particular point of the Earth's surface. Around this point we can imagine circles, along each of which the Sun appears at an altitude of 80° , or 70° and so on, at this same time.

Observing the altitude of the Sun at this time tells us that we must be somewhere on such a circle, according to the actual altitude which we have observed. These circles, determining our position, are called *position circles*.

If our observed altitude is not the same as the calculated one, we know that we are either farther away from or nearer to the point at which the Sun is directly overhead, as compared with the distance indicated by our D.R. Position.

As the navigator's position is always known with a greater or lesser accuracy, he need consider only a very small part of the position circle, that part which is near his D.R. Position. And, as these circles are usually of a very large diameter, he can further simplify the problem by considering that part of the circle as a straight line.

By observations of the sun at intervals of several hours, or observations of two stars at the same time, we obtain two such position lines, and the point of their intersection is the position of the ship at the time, and this navigators call a *fix*.

Assuming we had observed the Sun at an altitude of $43^{\circ}3'$ at 9.00 A.M., on a day when the Sun's declination was 20° North. Our D.R. Position was $51^{\circ}5'$ North, and situated on the Greenwich meridian, that is longitude $0^{\circ}0'$.

From a diagram like that of Fig. 35 we find that the Sun's altitude and azimuth at that time should have been: Alt. $43^{\circ}0'$, Azimuth S 65° E. The observed altitude is greater than this, and we are therefore nearer towards the point at which the Sun is overhead.

In order to fix our position, we draw two lines at right angles, representing the meridian and the parallel of latitude of our D.R. Position. Then we draw further lines, parallel to the meridian, at equal distances, representing the meridians of longitudes $10'$, $20'$, $30'$, and so on east and west of the D.R. Position.

As the meridians converge towards the pole, we have to find the right proportions between the distances of the meridians and between the parallels of latitude in order to make possible accurate measurements on our chart.

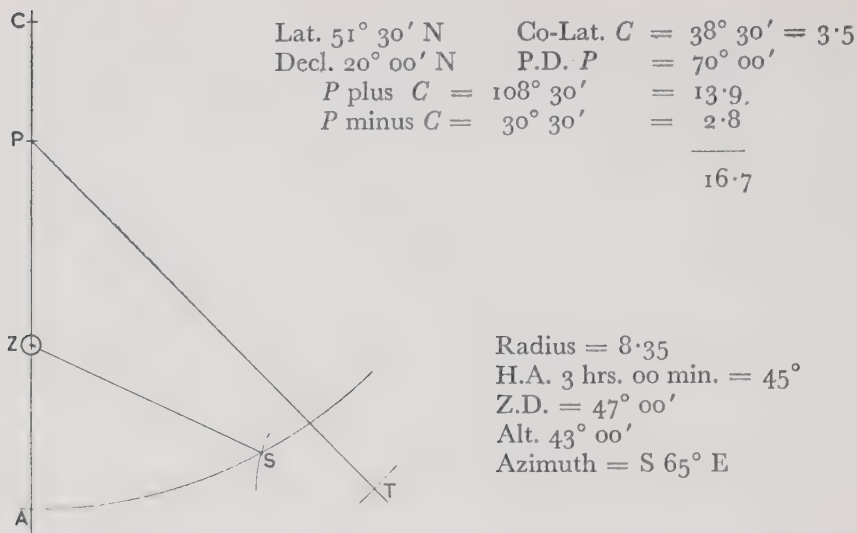


Fig. 35.

For this purpose we draw a line from the point O (see Fig. 36), making an angle with the parallel of latitude which is equal to our latitude. This line intersects the meridians, and the distances between the intersections are equal to as many degrees or minutes of latitude as the meridians are spaced in longitude. If we remember that one minute of latitude, at any point of the Earth's surface, equals one nautical mile, we are enabled to make measurements on this little chart.

Now we can draw a line from our D.R. Position at an angle which is equal to the Sun's azimuth which we have determined already. As the difference between the observed and the calculated altitude of the Sun was 0.3° , we know that our actual position is about 20 nautical miles towards the Sun, reckoned from the point O . If we measure this distance along that line, we can draw another one, at right angles to the first, in the point thus reached, and this latter is our position line. We must be somewhere on it, as all points on this line are 20 nautical miles nearer towards the Sun than is our D.R. Position.

If we observe the Sun again a few hours later, we obtain another position line, and this intersects the first. The point of intersection finally fixes our position on the surface of the Earth.

Is it surprising how accurate this method is, even if the calculations are made with our stereographic scale only, and the observations with our quadrant. Navigators with their sextants and bulky tables obtain an accuracy of about one nautical mile, but even our simple equipment enables us to obtain results which are correct within about six miles or so.

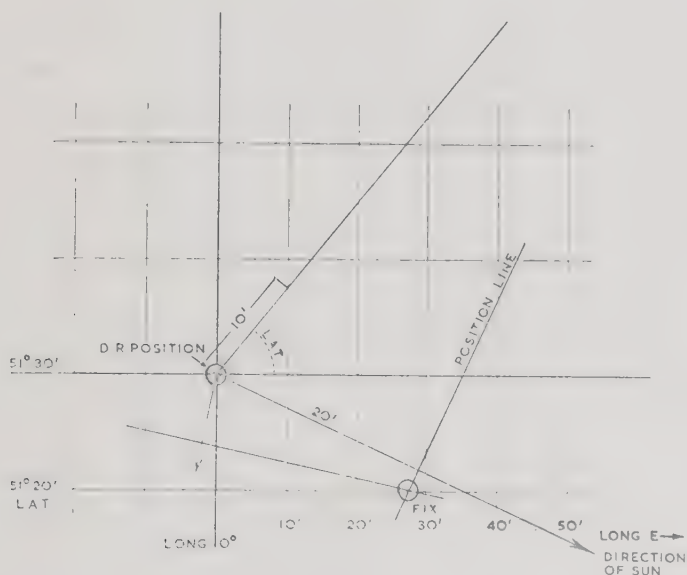


Fig. 36.	Calculated Alt.	43°
	minus Obs. Alt.	43° 20'
	minus	20'

Actual distance from the point where the Sun is overhead is 20' less than assumed. Actual position, therefore, is 20' towards the Sun, reckoned from the D.R. position

II

The Planets and Their Orbits

FOR THOUSANDS of years men have been puzzled by the strange movements of the planets, but a satisfactory explanation of these movements did not come forth until Copernicus published his revolutionary theory.

If we plot the path of a planet on a chart, we obtain such surprising results as the one pictured in Fig. 37, and even here some simplification has taken place already.

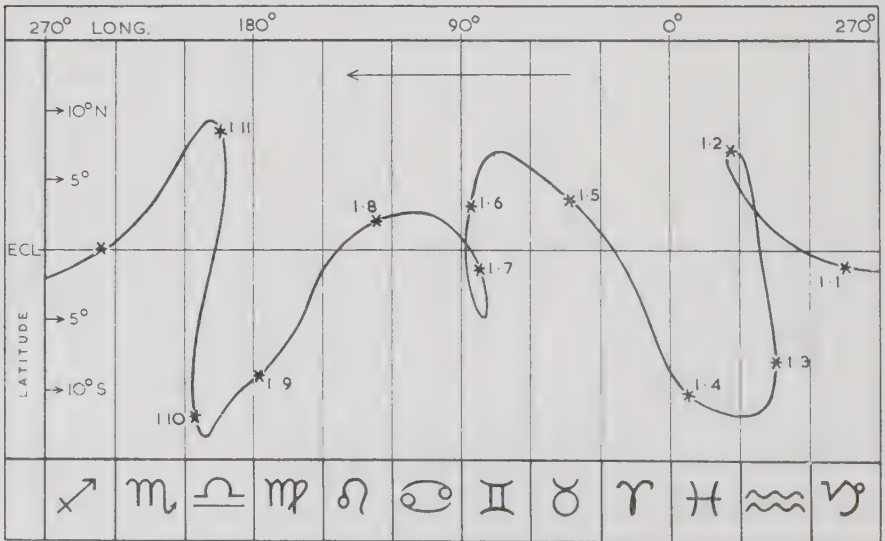


Fig. 37. Movement of Mercury in 1955

At the beginning of the year Mercury is in *direct motion*, that is, it moves from right to left across the sky, gains in latitude, and about 1 February its movement becomes retrograde (i.e. moves towards the right) and it describes a loop, quickly travelling towards the south. Within one month it reaches a position almost 15° farther south than that occupied on 1 February.

Afterwards the movement of the planet becomes direct once again, its longitude increases, and so does its latitude until it describes the next loop, during the month of June.

Mercury is particularly noted for such antics, but the other planets also describe loops and become retrograde at times, although their movements are slower than that of Mercury, because they are much farther away from the Sun, and therefore travel more slowly along their orbits.

The co-ordinates of the planet's position in Fig. 37 are given in a system different from those we already know. All planetary orbits and positions are, for convenience, referred to the ecliptic, which much simplifies the calculations, as the different declinations of the points of the ecliptic can be completely ignored.

In this system, the ecliptic longitude is equivalent to the R.A. of the celestial system, and this longitude is measured in degrees, starting from the First Point of Aries, and continuing in an anti-clockwise direction, along the ecliptic.

The declination also has its equivalent in the form of the ecliptic latitude, also measured in degrees, and this can either be north or south of the ecliptic.

The relationship between these two systems of co-ordinates is shown in graphic form in Fig. 44. With greater accuracy, measurements in one system can be expressed in terms of the other with the aid of the stereographic projection, drawing the two systems in their proper relationship, with the 'pole' of the ecliptic at a distance of $23\frac{1}{2}^\circ$ from the celestial North Pole. The angular measurements in the two systems both start at that intersection of the equator with the ecliptic where, going in an anti-clockwise direction, the ecliptic starts moving inside the circle representing the equator.

In Fig. 38 the movements of Mercury are pictured again, but this time the Sun has been chosen as the reference point, and the latitude of the planet has been ignored altogether. It is almost obvious that the planet circles around the Sun, and it is really surprising that the true nature of the planetary movements has not been realized earlier.

Let us consider this movement in detail. As seen from the Earth,

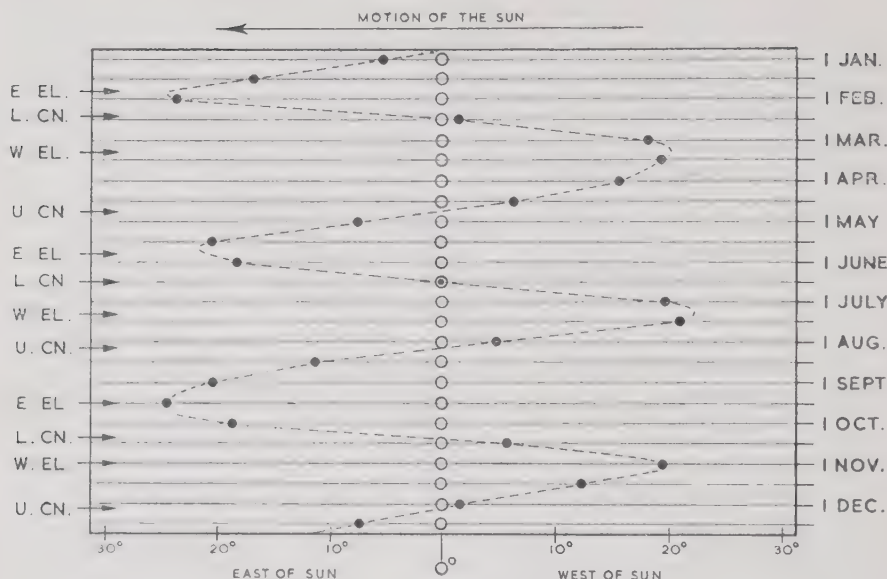


Fig. 38. Sun and Mercury in 1955

the planet will, of course, never be able to move farther away from the Sun than the diameter of its orbit will allow, taking into consideration the distance from which we observe it.

In the case of Mercury this is less than 30° , and this planet is therefore always near the Sun, and consequently difficult to observe. Johannes Kepler, in fact, told on his death bed that he had never in all his life been able to actually see this planet.

At the beginning of January 1955 we saw Mercury on the eastern side of the Sun, slowly moving away from it. (See Fig. 38.) Towards the end of that month the planet reached the point of its orbit which, to us, appears as the farthest point from the Sun, and this is known as the *Greatest Eastern Elongation*. After that, the planet approached the Sun again, passing between it and the Earth about the middle of February. The apparent meeting of the two celestial bodies is called a *conjunction*, and in the case of Mercury and Venus we distinguish between *upper* and *lower conjunctions*. In the former the planet is beyond the Sun, and in the latter it is between the Earth and the Sun.

The Greatest Western Elongation of Mercury occurs early in March, and then it moves towards the Sun again, this time passing it on the far side.

Mercury, and all the other planets, move around the Sun, and all the phenomena connected with their orbits, like the loops which they describe, or the fact that they sometimes retrace part of their path, only to resume the proper direction soon afterwards, can be explained by this movement and the fact that the Earth also travels along a similar orbit and is not fixed in space.

THE ORBIT OF A PLANET

The actual orbit which a planet describes around the Sun—as distinct from the apparant path as seen from the Earth—has the shape of an ellipse. The ellipse, like a circle, has a centre, O (see Fig. 40), and every straight line passing through it is called a diameter of the ellipse. The diameters of a circle are all equal, but those of an ellipse have different lengths. The greatest diameter, $A-A'$, is called the *major axis*, and the smallest, $B-B'$, the *minor axis*. These two are perpendicular to each other.

If we describe an arc around the point B , the diameter of which is equal to half the length of the major axis, it cuts this in two points F and F' , the two *foci* of the ellipse. Any point of the ellipse, say, C , can be connected with the two foci, and the total length of the two lines is always equal to the length of the whole of the major axis, whichever point of the ellipse was chosen.

The ratio of the distance of one focus from the centre of the ellipse to the length of half the major axis is called the *eccentricity* of the ellipse, and this is usually denoted by the small letter e .

From the properties of the ellipse it follows that both its shape as well as its size are fully defined if a (length of half the major axis) and e

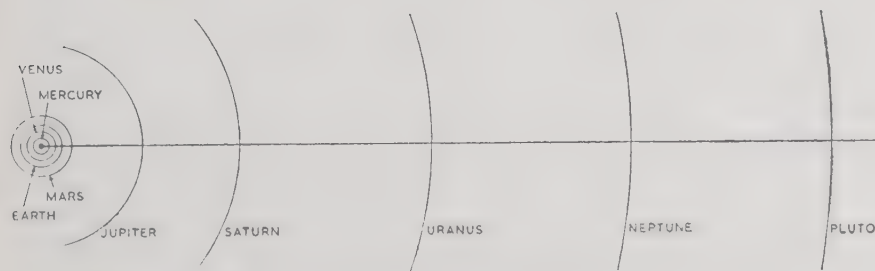


Fig. 39. Average distances of the planets from the Sun

(excentricity) are known, and the ellipse can be constructed if numerical values for these are given.

The excentricities of the orbits of the different planets differ as widely as do the lengths of their semi-major axes. Excentricities range from 0.0068 (Venus, whose orbit most closely approaches the shape of a circle) to 0.249 (Pluto).

The semi-major axes can be considered to be the average distances of the planets from the Sun, and as the standard for comparison that of the Earth has been chosen as the unit of length for measuring distances within the Solar System. The average distance of the Earth from the Sun is called the *astronomical unit*. Mercury, closest to the Sun, is 0.39 astr. units away from the Sun, and Pluto, the outermost planet of our system, is, on the average, 39.5 astr. units away from it.

KEPLER'S LAWS

The laws of planetary motion were discovered by Kepler, who stated them in the following way:

FIRST LAW: The orbit of a planet is an ellipse, with the Sun situated at one focus.

SECOND LAW: The movement of the planet is such that the line connecting the Sun with the planet (this line is called the *radius vector*) traces out equal areas in equal time intervals.

THIRD LAW: The square of a planet's period of rotation is proportional to the cube of the semi-major axis of its orbit.

The actual distance of a planet from the Sun obviously differs greatly, according to the part of its orbit which the planet is occupying. If we consider the Sun to be in the point *F* (Fig. 40), the point *A* would be that point of the planet's orbit which is nearest to the Sun, and this point is called the *perihelion* (*Peri*=Near, *Helios*=Sun, both words of Greek origin). *A'*, farthest point of the orbit, is the *aphelion*.

As the planet's period of rotation is dependent on the length of the semi-major axis of its orbit, it is sufficient to know *a*, *e*, and the *epoch*, which is the time at which a planet occupies a specified point of its orbit, to find its position at any given moment, if the second of Kepler's Laws is applied for these calculations.

This, however, does not tell us where in the sky we have to look for the planet, as the position of its orbit has to be known as well. For this we need another three figures, and a system of reference.

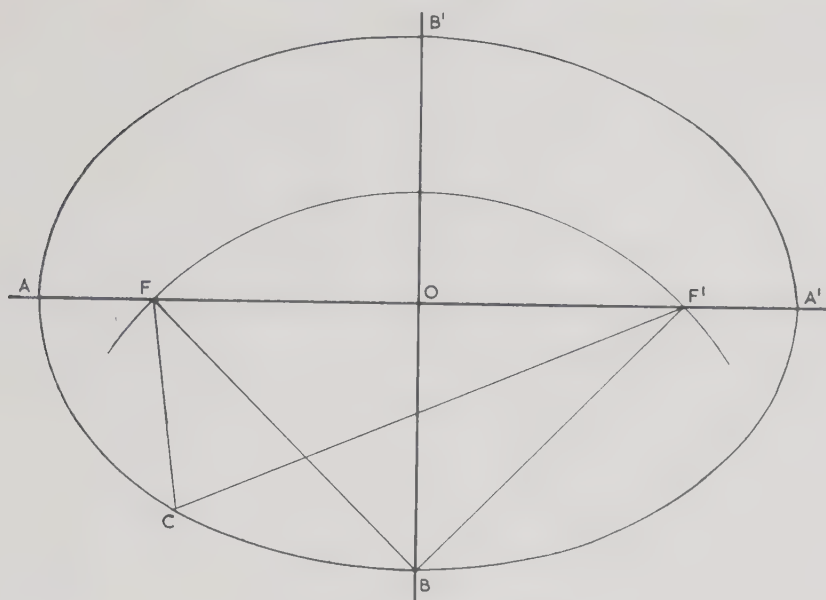


Fig. 40. The ellipse

It is most convenient to choose the ecliptic as the plane of reference, and we can state which angle the plane of the planet's orbit makes with that of the ecliptic. This angle, called the *inclination of the orbit*, is denoted by the small letter i .

There are two points in the planet's orbit in which it intersects the plane of the ecliptic; one of these is passed by the planet while it is going UP, from south to north of the ecliptic, and this is called the *ascending node*, and the other, *descending node*, is passed by the planet when going DOWN. The line connecting the two nodes passes through the Sun, and is called the *line of nodes*. It lies in the plane of the ecliptic and its direction is fixed by stating which angle the ascending node makes with the First Point of Aries. This angle is usually denoted by the sign Ω (*read: node*).

These two measurements fix the plane of the planet's orbit with reference to the ecliptic, and to fix the actual orbit we only have to know one more measurement, which is the angle ω (*omega*) which the line connecting the Sun with the planet's perihel makes with the line of the ascending node.

THE PROBLEM

With these six quantities we have all the requisites necessary for the solution of that problem which is of greatest importance in practical astronomy, namely that of calculating the position in the sky which a planet will occupy at a given time.

This entails the calculation of three quantities: first, the distance of the planet from the Sun; secondly, the latitude, that is the angular distance above or below the ecliptic; and lastly the ecliptic longitude of the planet, that is the direction from the Sun in which it is situated.

When the planet is in that part of its orbit which is half-way between the nodes, its latitude is either at its maximum or at its minimum, and it then equals the inclination of the orbit. The planet's latitude is zero when it is situated at one of the nodes, and in intermediate positions the latitude is of a value somewhere between the extremes.

The longitude should, of course, be reckoned along the planet's actual orbit, in its proper plane, but as the inclinations of the planetary orbits are comparatively small only, we can safely assume that the orbital and the ecliptic longitudes are the same, at least within the accuracy which we require.

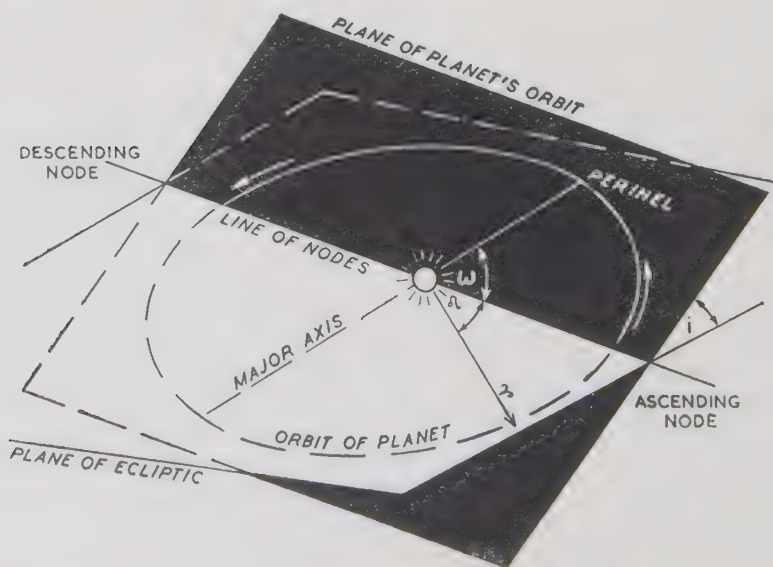


Fig. 41. The elements of a planet's orbit

THE SOLUTION

For the calculation of a planet's position we use the charts at the end of this chapter. These give us all the necessary data, and the actual procedure of calculating such a position is quite simple.

Our starting date, the *epoch*, for all the calculations is 1950, 0 January, 00 hrs. G.M.T. This, in civil language, is the same as 0 A.M. on 31 December 1949. The reason for writing the date of the epoch in a different manner becomes obvious when we add the numbers of years, months and days. In illustration of the method we shall calculate the position of Venus, as seen from the Earth, on 13 November 1955 at 0 hrs. G.M.T.

At the starting date, the longitude of Venus is $80^{\circ} 85'$, and to this we add the increment for 5 years, which we take from the table. This is $43^{\circ} 89'$, which ignores, however, a number of complete revolutions which the planet has made during that interval. As the year 1952 was a leap year with one additional day, we have to add one day's increment to the figures. Then we add the increments for the month of November, and for 13 days, and we arrive at the total of $274^{\circ} 24'$, and this we call the *mean longitude* of the planet.

We can now see the reason for the way in which the date of our epoch was written. We thus simply add the difference between the year in question and the starting year, without any further calculations, and the actual starting date being 31 December makes it possible to always add the number of days according to the current date. If we had chosen 1 January for our starting date, we would have to subtract one day from each date which we wanted to enter into our calculations.

Quite frequently it will happen that our results give us angles which are much in excess of 360° , indicating that the planet has made more than a full revolution, and in order to simplify our figures we can always subtract 360° or multiples thereof whenever it is possible. 360° constitutes a full revolution, and subtracting this figure from our results makes no difference at all to the actual longitude.

We have so far arrived at the mean position of the planet only, that is, the position it would occupy if the speed with which it travels along its path were uniform. The orbit, however, is an ellipse, and the speed therefore varies with the position of the planet in its orbit. Sometimes the planet will be in advance of the mean position, and sometimes it will be behind. The amount of the difference is a fixed quantity for every point of the orbit, and it is called the *equation of the centre*. The magnitude of this can be taken from the graph on our chart.

In our example we find that the equation of the centre of Venus, for a mean longitude of $274^{\circ}24'$, is plus 0.5 degrees, and we therefore have to add this to the mean in order to obtain the true longitude.

With this true longitude we enter the other two graphs, and find that the distance of Venus from the Sun is 0.73 astr. units on that day, and the latitude minus 1° .

These figures express the position of Venus as seen from the Sun, and in order to find the place in the sky where Venus appears when seen from the Earth we have to repeat the same calculation for the Earth as well. The two calculations are, for the sake of convenience, best written side by side, and our figures should look like this:

1955, 13 November, 0 hrs., G.M.T.

	VENUS		EARTH
Epoch:	<u>80.9</u>		<u>99.2</u>
5 Years:	43.9		358.7
1 Day:	1.6		1.0
November:	127.1		299.6
13 Days:	<u>20.8</u>		<u>12.8</u>
			771.3
		minus	<u>720</u>
Mean Long.:	274.3		51.3
Eq. Centre:	<u>0.5</u>	minus	<u>1.5</u>
True Long.:	<u>274.8</u>		<u>49.8</u>
Dist.:	<u>0.73</u>	a.U.	<u>0.99</u> a.U.
Lat.:	minus 1.0°		

Having calculated these figures, we can now make a diagram like Fig. 42, entering the Earth's and the planet's positions, according to their longitudes and distances from the Sun, relative to the Sun and the First Point of Aries. By connecting the position of the Earth with that of the planet, we obtain the direction into which we have to look in order to find the planet in the sky. This line of sight, however, does not meet the outer circle of our diagram at the point which indicates the proper direction, or, as it is called, the *apparent longitude*, because this outer circle should be so large that the planetary distances become insignificant. This condition can be realized by drawing a line from the Sun, exactly parallel to our line of sight, and this will then indicate on the outer circle the ecliptic longitude in which we shall find the planet. In our example this turns out to be 251° .

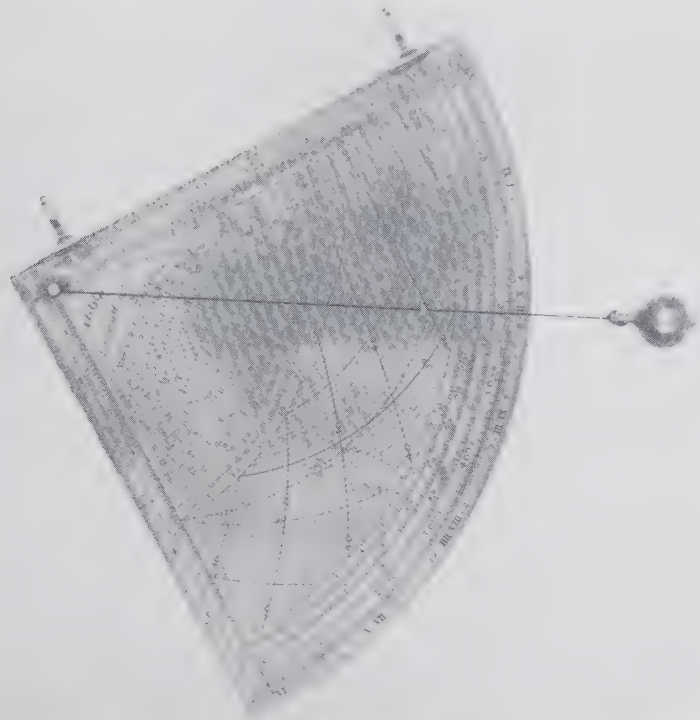


PLATE VII. Orrery made by Henry Sutton in 1696, with a projection of part of the sky, for use as a sun or star dial, also with perpetual calendar and various other scales.

Orrery Collection, Christ Church, Oxford

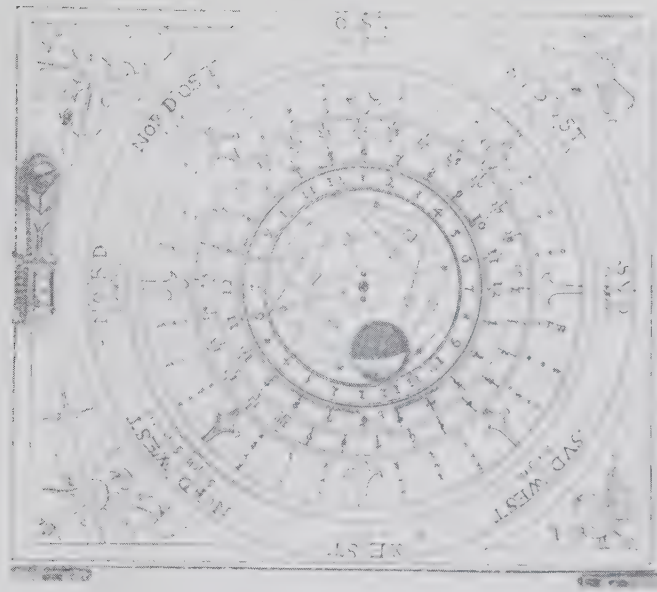


PLATE VIII. German Volvelle made in 1613. By setting the inner disc, this instrument indicates the age and phase of the Moon.

By courtesy of the Curator of the Museum of the History of Science, Oxford

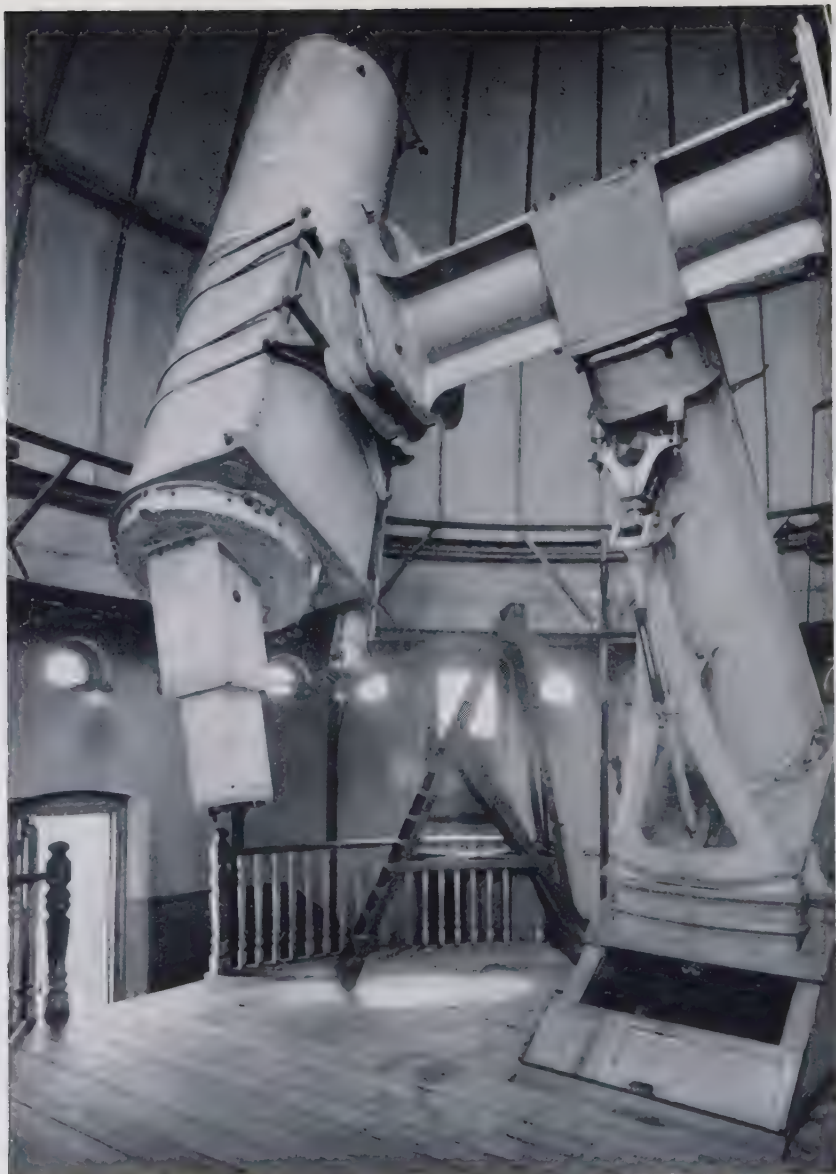


PLATE IX. Thirty-inch reflecting telescope of the Royal Greenwich Observatory.

Royal Observatory, Greenwich

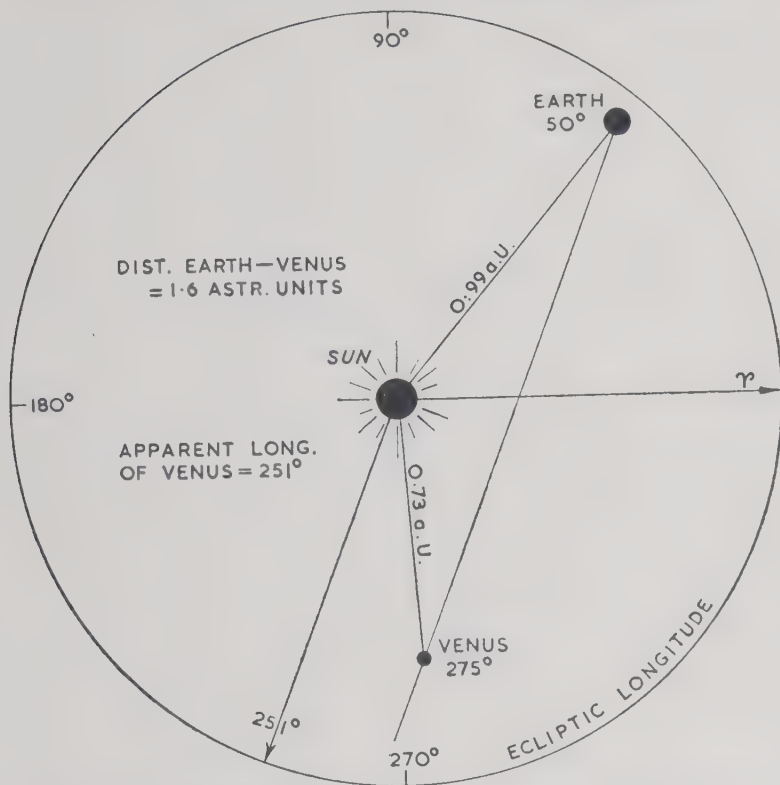


Fig. 42. Apparent longitude of Venus, as seen from the Earth on 13 November 1955, 0 hrs. G.M.T.

The latitude of Venus is measured in degrees, and this is the angle which the planet makes at the Sun with the ecliptic, but it is obvious that, seen from the Earth, its latitude appears to be different, as we do not see Venus from the same distance.

This problem has been illustrated in Fig. 43. The angle at the Sun which Venus makes with the ecliptic is 1° , and its distance is 0.73 astr. units. We draw a diagram and, for the sake of greater accuracy, we make the angle ten times as great, that is, the line connecting Venus with the Sun makes an angle of 10° with the ecliptic in our drawing.

Mathematically, this is not quite correct, but the difficulties of constructing and measuring an angle of the correct value would make the result so inaccurate as to be of no value at all. It is thus better to put



Fig. 43. The apparent latitude of Venus

up with the slight error introduced by this misrepresentation, but arriving at a useful result, even if it is not quite correct. The inaccuracy is so small as to make no difference, aiming, as we do, at figures which are exact to the first decimal only.

In our first diagram (Fig. 42), we measure the distance between the Earth and the planet, and express this in terms of astronomical units, according to what scale we have employed. This distance is then marked on the other side of the planet's position in our second diagram (Fig. 43) and the point thus obtained represents the Earth at its relative distance from the planet. Now we can measure the angle which Venus makes at the Earth with the ecliptic. In our case this will be found to be 4° , and we have to divide this by ten, as we have made the first angle ten times as large as it actually should be. Venus, thus, is rather less than $\frac{1}{2}^\circ$ below the ecliptic, at the longitude of 251° .

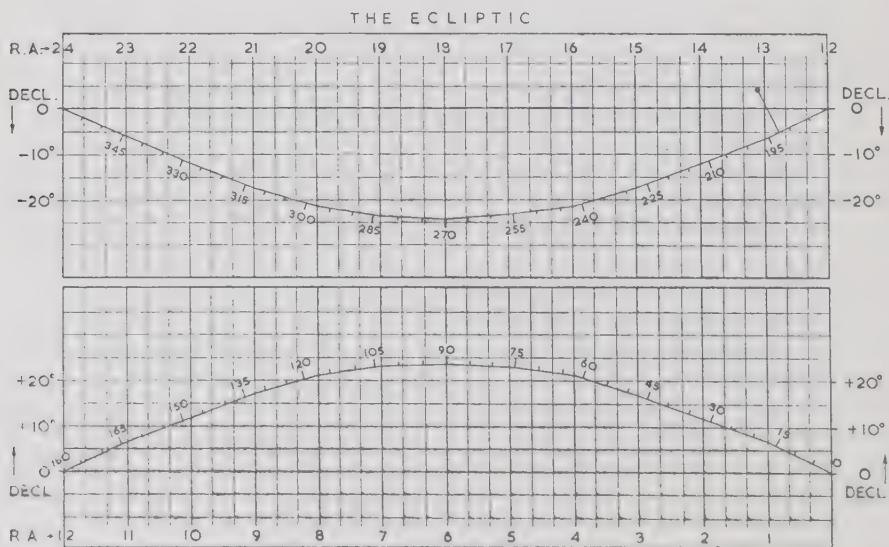
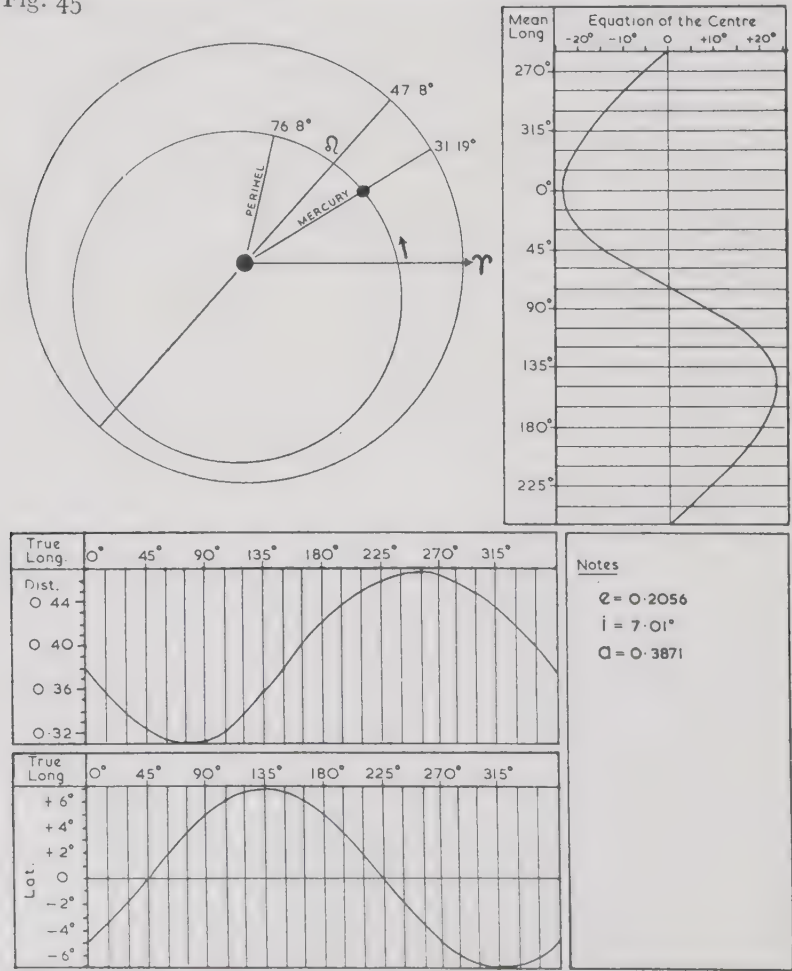


Fig. 44. The co-ordinates of the ecliptic

The co-ordinates of the ecliptic, in terms of R.A. and decl., are shown in Fig. 44. The result of our calculations enables us to mark the planet's position in respect to the ecliptic on this chart, and at the edges of this we can then read off the R.A. and decl. of the planet. We will find that the R.A. of Venus on that day is 16 hrs., 38 mins., and its decl. is minus 22° . By comparing this result with our star map, we find that Venus, on 13 November 1955, is situated in the lower part of the constellation Ophiuchus, about 5° North, and a little to the East of the bright star Antares in Scorpio. As Venus is also rather a bright object, the two should make a fine pair, especially as Venus is pure white, and Antares is reddish. Unfortunately, however, on that day they are so near to the Sun that they can be observed only with a telescope or with binoculars, at the time of sunset in the South-west, and almost on the horizon.

M E R C U R Y				
Epoch: 1950, January 0, 0 hrs. G.M.T.				
Daily Motion: 4.0923°				
2 days:	8.18			
3	12.28			
4	16.37			
5	20.46			
6	24.55			
7	28.65			
8	32.74			
9	36.83			
10	40.92			
			Add for 1 year: 53.70° 2 years: 107.41 3 161.11 4 214.81 5 268.52 10 177.04 20 354.07 30 171.11 40 348.15 50 165.19 Add one day for each leap year since 1950	Add for January 0.00° February 126.87 March 241.46 April 8.32 May 131.09 June 257.96 July 20.72 August 147.59 September 274.46 October 37.22 November 164.09 December 286.86

Fig. 45



VENUS

Epoch: 1950, January 0,
0 hrs. G.M.T.

Daily Motion:	1.6021°
2 days:	3.20
3	4.81
4	6.41
5	8.01
6	9.61
7	11.21
8	12.82
9	14.42
10	16.02

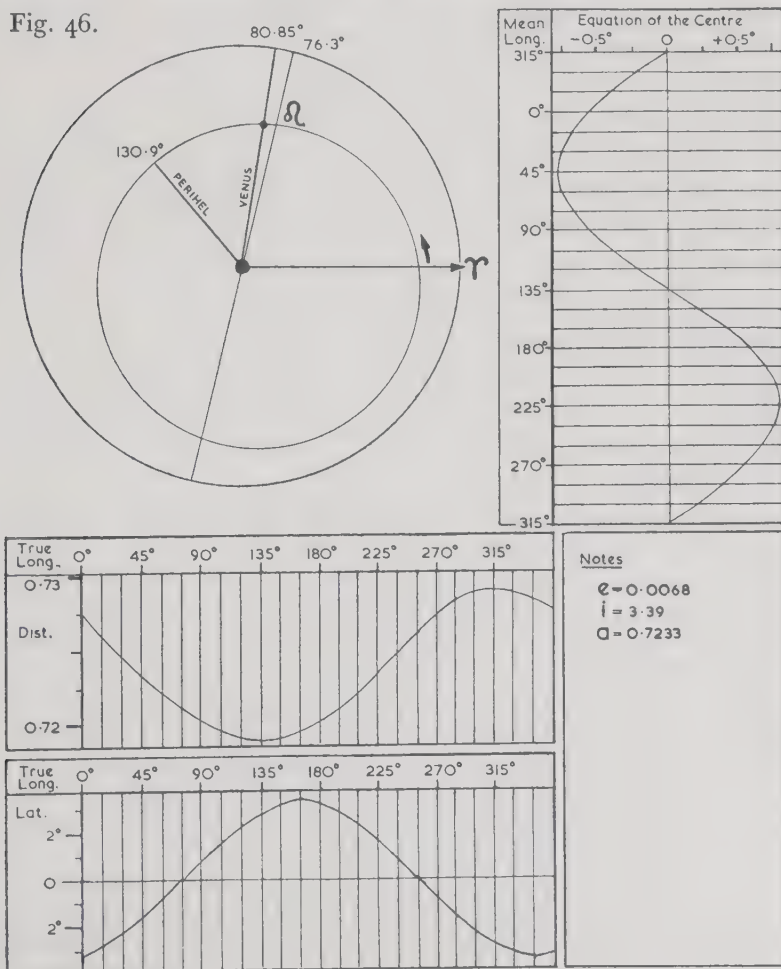
Add for

1 year:	224.78°
2 years:	89.56
3	314.33
4	179.11
5	43.89
10	87.78
20	175.56
30	263.33
40	351.11
50	78.89
Add one day for each leap year since 1950	

Add for

January	0.00°
February	49.67
March	94.54
April	144.21
May	192.27
June	241.94
July	290.00
August	339.67
September	29.34
October	77.41
November	127.07
December	175.12

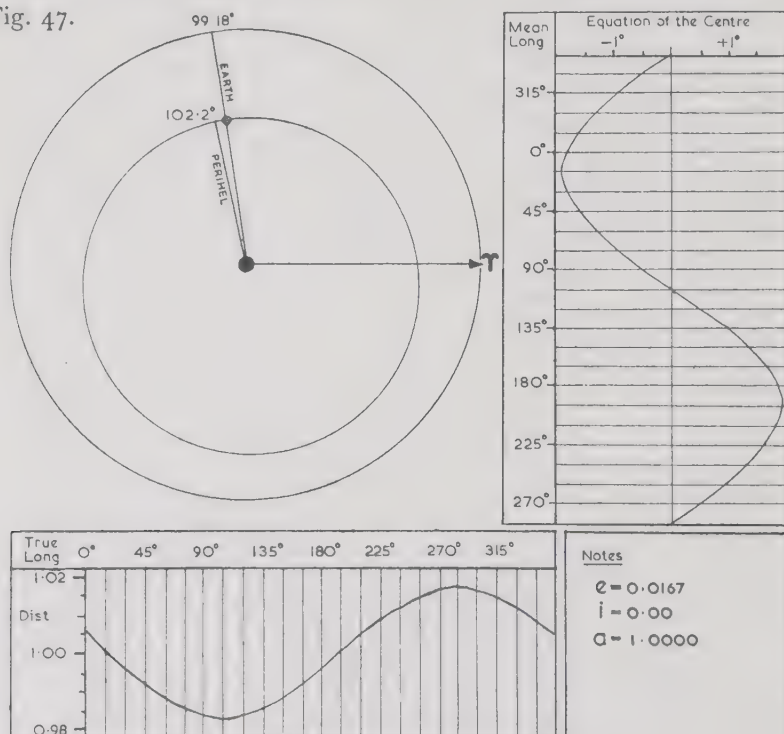
Fig. 46.



EARTH	
Epoch: 1950, January 0, 0 hrs. G.M.T.	
Daily Motion:	0.9856°
2 days:	1.97
3	2.96
4	3.94
5	4.93
6	5.91
7	6.90
8	7.88
9	8.87
10	9.86

Add for		Add for	
1 year:	359.75°	January	0.00°
2 years:	359.49	February	30.56
3	359.24	March	58.16
4	358.99	April	88.72
5	358.74	May	118.29
10	357.47	June	148.84
20	354.95	July	178.41
30	352.42	August	208.96
40	349.89	September	239.52
50	347.36	October	269.09
Add one day for each year since 1950		November	299.64
		December	329.21

Fig. 47.



As the Earth's orbit provides the plane of reference from which the latitudes of the other planets are reckoned, the Earth's latitude is always zero, and the Earth's orbit has no nodes.

MARS

Epoch: 1950, January 0,
0 hrs. G.M.T.

Daily Motion:	0°5240'
2 days:	1°05'
3	1°57'
4	2°10'
5	2°62'
6	3°14'
7	3°67'
8	4°19'
9	4°72'
10	5°24'

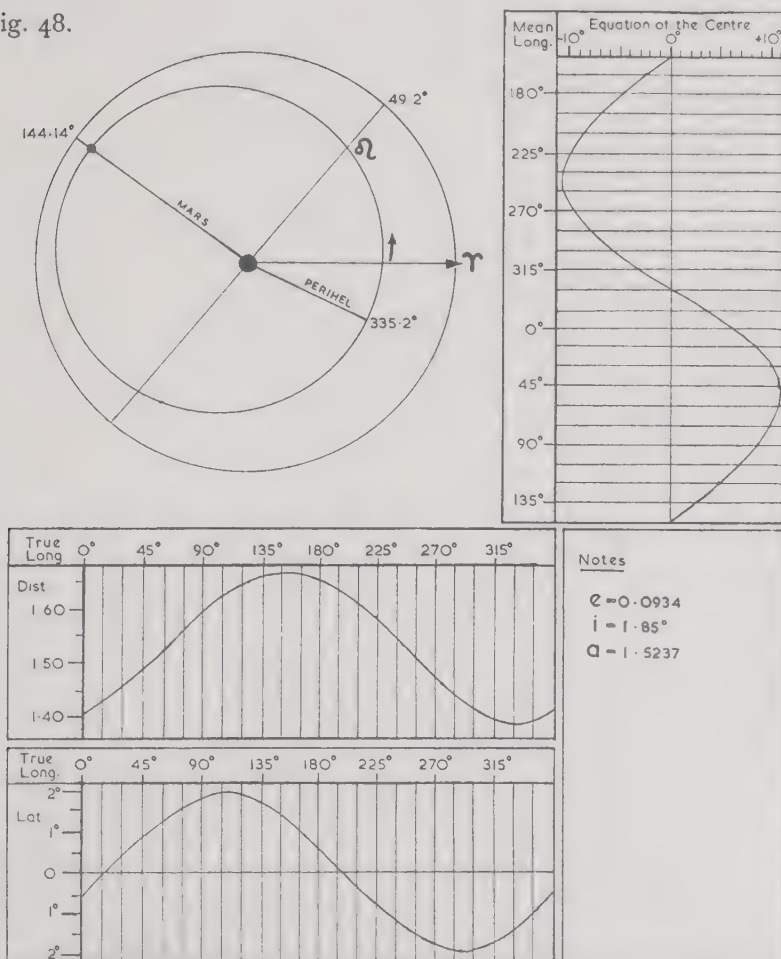
Add for

1 year:	191°27'
2 years:	22°54'
3	213°82'
4	45°09'
5	236°36'
10	112°72'
20	225°44'
30	338°16'
40	90°88'
50	203°60'
Add one day for each leap year since 1950	

Add for

January	0°00'
February	16°26'
March	30°92'
April	47°17'
May	62°89'
June	79°14'
July	94°86'
August	111°11'
September	127°36'
October	143°07'
November	159°32'
December	175°04'

Fig. 48.



JUPITER

Epoch: 1950, January 0,
0 hrs. G.M.T.

Daily Motion:	0.0831°
2 days:	0.17
3	0.25
4	0.33
5	0.42
6	0.50
7	0.58
8	0.66
9	0.75
10	0.83

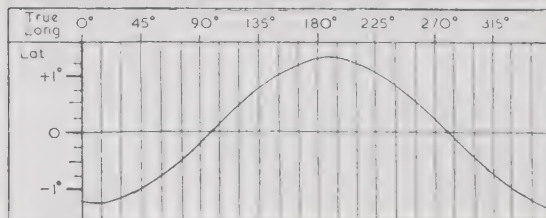
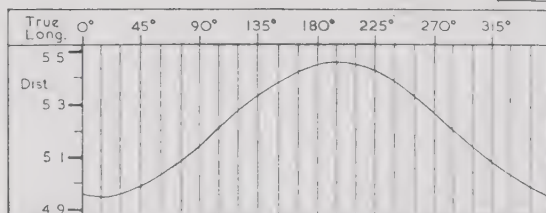
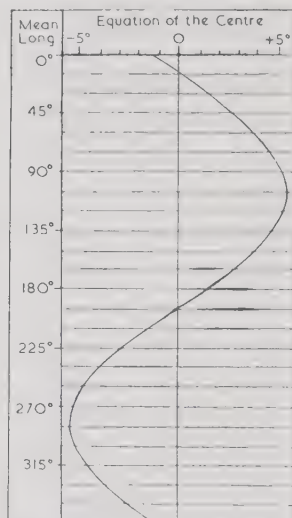
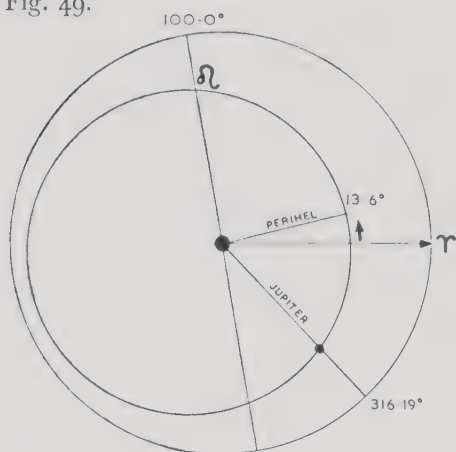
Add for

1 year:	30.33°
2 years:	60.66°
3	90.98°
4	121.31°
5	151.64°
10	303.28°
20	246.56°
30	189.85°
40	133.13°
50	76.41°
Add one day for each leap year since 1950	

Add for

January	0.00°
February	2.42°
March	4.91°
April	7.49°
May	9.99°
June	12.56°
July	15.06°
August	17.62°
September	20.21°
October	22.71°
November	25.27°
December	27.72°

Fig. 49.



Notes

$$e = 0.0484$$

$$i = 1.31$$

$$Q = 5.2028$$

SATURN

Epoch: 1950, January 0,
0 hrs. G.M.T.

Daily Motion:	0.0335°
2 days:	0.07
3	0.10
4	0.13
5	0.17
6	0.20
7	0.23
8	0.27
9	0.30
10	0.33

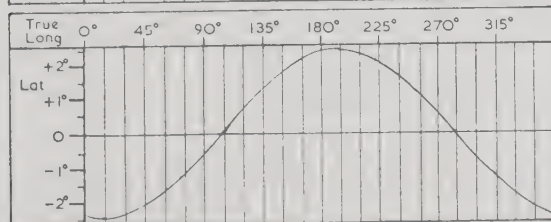
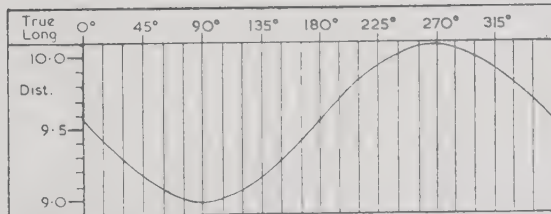
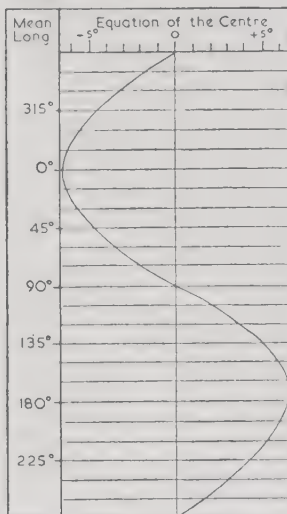
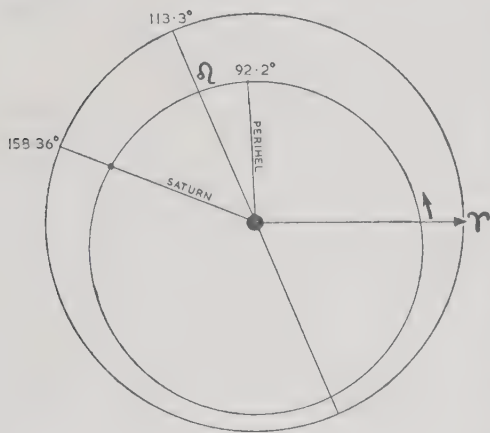
Add for

1 year:	12.21°
2 years:	24.43
3	36.64
4	48.85
5	61.06
10	122.13
20	244.26
30	6.39
40	128.52
50	250.65
Add one day for each leap year since 1950	

Add for

January	0.00°
February	1.04
March	1.99
April	3.02
May	4.02
June	5.07
July	6.07
August	7.10
September	8.14
October	9.15
November	10.18
December	11.19

Fig. 50.



Notes

$$e = 0.0557$$

$$i = 2.50$$

$$Q = 9.5388$$

U R A N U S

Uranus

Epoch: 1950, January 0,
0 hrs. G.M.T.

Daily Motion: 0°01'17"

5 days: 0°06'

10 0°12'

Add for

1 year: 4°28'

2 years: 8°56'

3 12°85'

4 17°13'

5 21°41'

10 42°82'

20 85°64'

30 128°47'

40 171°29'

50 214°11'

Add one day for each leap
year since 1950

Add for

January 0°00'

February 0°38'

March 0°71'

April 1°08'

May 1°43'

June 1°79'

July 2°14'

August 2°50'

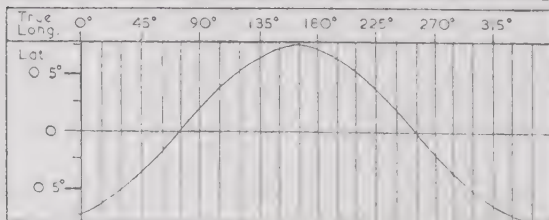
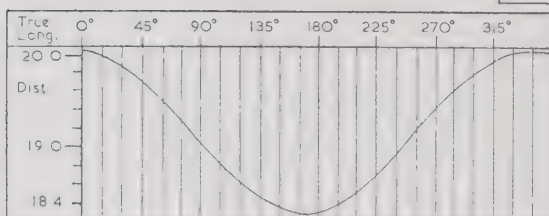
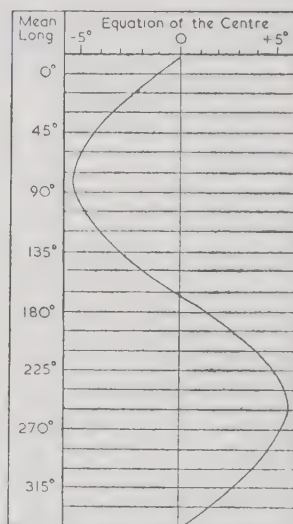
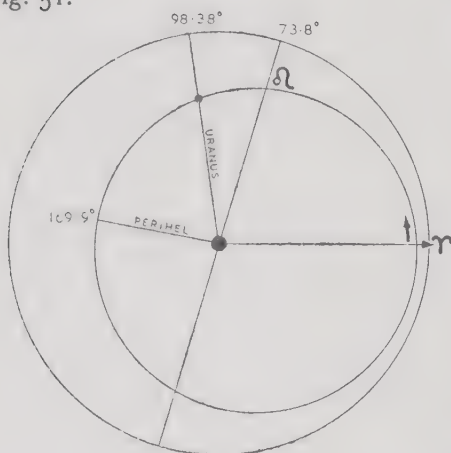
September 2°88'

October 3°23'

November 3°59'

December 3°94'

Fig. 51.



Notes

$e = 0.0472$

$i = 0.78$

$Q = 19.1820$

12

The Moon

AMONG ALL the heavenly bodies belonging to our Solar System the Moon is by far the fastest, so fast, in fact, that a patient observer can see her move among the stars, travelling, every hour, a distance which is about equal to her own diameter—a little over $\frac{1}{2}$ degree.

Although the velocity of the Moon in her orbit is not very spectacular as compared with other bodies—she travels about $\frac{2}{3}$ of a mile per second—she appears, to us, faster than any of the others simply because the Moon is our nearest neighbour in space.

Circling the Earth at an average distance of 238,850 miles, the Moon moves, like the planets, from West to East among the stars, completing the journey around the sky once every 27.3 days. According to her position in relation to the Earth and to the Sun, we see a greater or lesser part of her surface illuminated by the Sun, and her ever-changing position causes the succession of the phases.

Position 1 in Fig. 52 is that at New Moon, when she is in the same direction—as seen from the Earth—as is the Sun, and its dark side is turned towards us.

A few days later, the Moon reaches position 2, and we see her in the evening sky with part of her disk, on the western side, illuminated. About one week after New Moon, exactly half of the Moon's surface is illuminated and she is then said to be in the First Quarter.

Full Moon occurs when the Moon is in *opposition* to the Sun, that is when she is exactly on the opposite side of the sky. Her angular distance from the Sun, measured along the ecliptic, is then 180° . This happens about $14\frac{3}{4}$ days after New Moon, and the Moon then rises at about the same time as the Sun sets.

After Full Moon, the Moon disappears from the evening sky, and becomes visible in the mornings, showing us the eastern side of her face

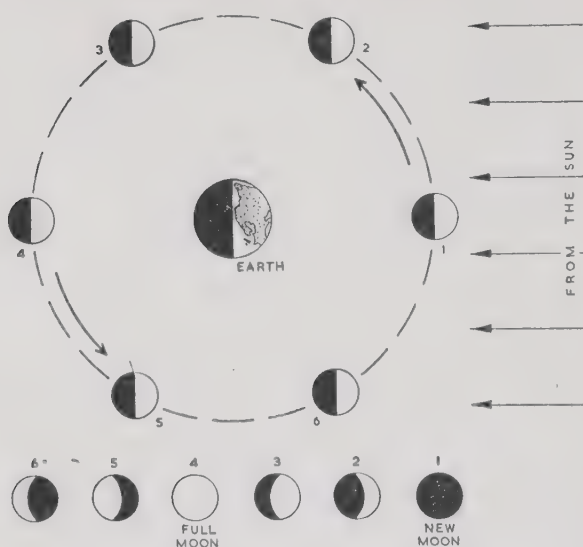


Fig. 52. The phases of the Moon

illuminated, until, $29\frac{1}{2}$ days after New Moon, position 1 is reached once again, and the Moon is invisible to us.

The time from Full Moon to Full Moon is over two days longer than the time it takes the Moon to make one revolution with respect to the stars. As the Earth travels around the Sun, it covers some distance during the interval of 27·3 days, and the Moon has to make up this distance, in order to get in the position opposite the Sun again. This, then, accounts for the difference between the two periods.

The phases of the Moon, and her position in the sky relative to the Sun and the Earth, are very well illustrated by a medieval instrument which is called a *volvelle*. One of these instruments is shown on Plate VIII and its construction is explained in Fig. 53.

The base-plate of the volvelle is marked with the names of the months and the zodiacal signs through which both the Sun and the Moon travel. On top of this disk is another one, revolving around its centre, and the index of this can be set against the date shown on the base-plate. This second disk is black in the centre, with a heart-shaped area left white, and around its edge are marked the figures from 1 to 29.

The third disk, situated on top of the second, also has an index, which is set to the constellation in which the Moon is observed. The

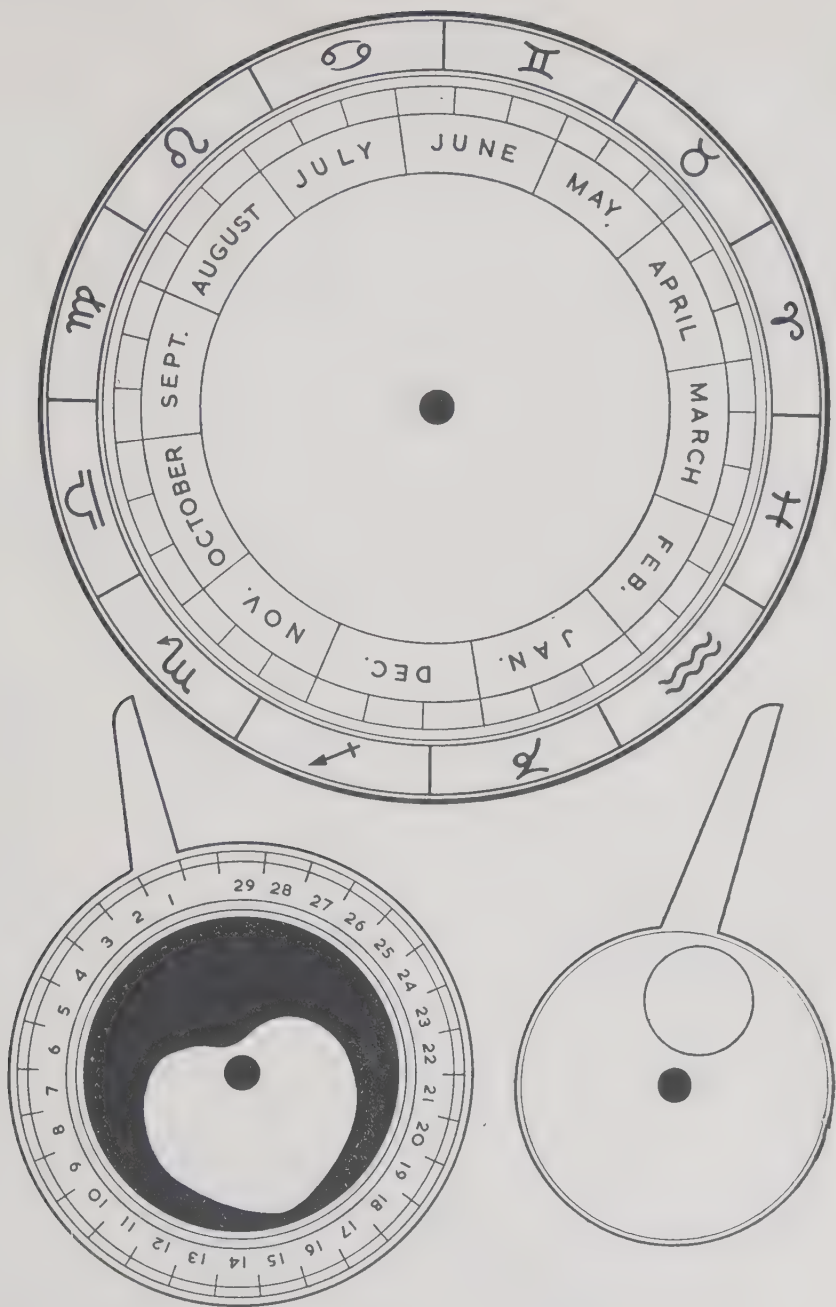


Fig. 53. The part of a volvelle

index then marks the age of the Moon, indicating it among the figures on the edge of the second disk, and in the circular aperture the heart-shaped figure produces the approximate shape of the Moon.

This volvelle can, of course, be set either by the sign in which the Moon is observed, or by her age, or by the shape shown. In either case it indicates automatically the other two.

Medieval volvelles were rather elaborate instruments, usually engraved on brass. They had figures and circles marked on them which were used for the solution of a variety of astronomical problems. The zodiacal constellations were usually represented as on a star map, and in the calendar-circle were indicated the dates of the festivals and holy days. Volvelles were, in fact, a sort of perpetual calendar, and their elaborate design made them rather costly instruments, but quite a simple one is easy to construct; all the necessary details are shown in Fig. 53. It is rather good fun to try how exactly a volvelle can be made to represent the actual path of the Moon in the sky, and with what accuracy it will show the phase of the Moon.

THE ORBIT OF THE MOON

Like the planets, the Moon always keeps near the ecliptic, never departing more than about 5° from it, and crossing it twice every time

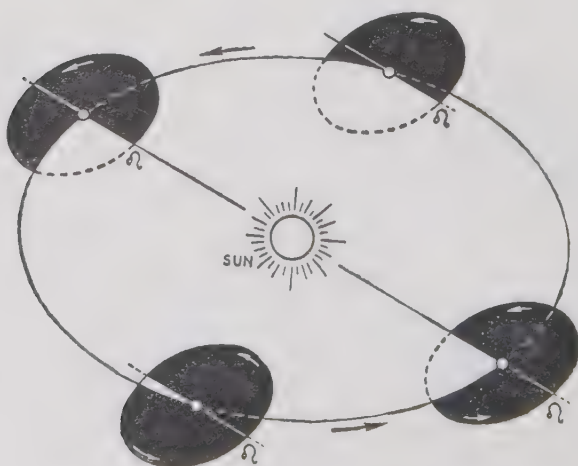


Fig. 54. Orbits of the Earth and the Moon



Fig. 55. The Full Moon is always opposite the Sun

she circles the Earth. Thus, half of her monthly journey takes place north, and the other half south of the ecliptic. The points where she crosses the ecliptic are again called the nodes, and we have one ascending and one descending node.

The orbit of the Moon is taken around by the Earth on its yearly journey around the Sun. The line of nodes, however, does not point at the same point of the sky all the time, but neither does it point towards the Sun. Let us consider what happens here. Assuming that the orbit were fixed in space, the Moon would be above the plane of the ecliptic before reaching the descending node, and the Earth's gravitational pull tends to pull the Moon down to the plane of the ecliptic. The Moon, therefore, reaches this plane a little earlier than she would if she could pursue her course undisturbedly. The same happens before she reaches the ascending node, and the result of this is that the nodes, with each revolution of the Moon, travel a little towards her.

The line of nodes, thus, slowly retrogrades, that is, turns in the direction opposite to the Moon's movement, completing one full circle of 360° in a little over $18\frac{1}{2}$ years.

As Sun and Full Moon are always on opposite sides of the sky, it follows that the winter Full Moon is high up in the sky, more or less in a position which the Sun would occupy in the summer, and the summer Full Moon is always low, near the horizon.

Every $18\frac{1}{2}$ years it happens that the ascending node of the Moon's orbit coincides with the First Point of Aries, and then the highest part of the Moon's orbit is even above the highest point of the ecliptic. The lowest part of the Moon's orbit then is even below the lowest point of the ecliptic, and it thus happens that the winter Full Moon is about 5 degrees above the point which the Sun occupies in the summer. The Moon then dips below the horizon for only a few hours every day, while in the summer afterwards the Full Moon is 5 degrees below the position which the Sun occupies on the shortest day of the year, with

the result that the Moon becomes visible only for a few hours around midnight.

Nine years later the line of nodes has made half a revolution, and the position is then reversed. The winter Full Moon is about 10 degrees lower in the sky than the winter Full Moon of 9 years before, and the summer Full Moon is 10 degrees higher above the horizon.

The Moon's path around the Earth, like that of a planet around the Sun, is an ellipse. The point nearest to the Earth, comparable to the perihelion of a planetary orbit, is called the *perigee*, and this, like the line of nodes, is not fixed in space either, as is the case with both of them if they are of the orbit of a planet. The direction of the Moon's perigee traces out a full circle around the sky every 8.9 years, and the direction of its movement is direct, that is, it travels along the Moon's orbit in the same direction as the Moon herself.

THE MOTION OF THE MOON

To an independent observer in space, the Moon would not appear to travel around the Earth, but, with the Earth, around the Sun. This is not at all surprising because the force acting on the Moon, which is due to the Earth's gravitational pull, is only about half that which is due to the Sun. As there are thus two bodies which govern the movements of the Moon, the irregularities of her orbit find some explanation.

Although the Moon apparently travels around the Earth, which, in turn, travels around the Sun, the Moon's resulting path does not consist of a series of loops, but is an ellipse which has the Sun at one of its foci, and all the Earth can do is to make her move a little in or out of that ellipse, and make her move a little faster or slower at different parts of her orbit, which gives us the appearance of an elliptical orbit around the earth.

At no point, however, is the actual orbit of the Moon 'bulging' towards the Sun; it always presents the 'hollow' side to it.

But let us consider the motion of the Moon along the apparent elliptical orbit around the Earth. The calculation of the Moon's position in the sky, naturally, involves the determination of the position of the orbit at the time, apart from the calculation of the Moon's position in that orbit.

Because of the influence of the Sun, the Moon's position in the sky is not calculated quite as easily as that of a planet, even if we disregard the fact that, first of all, we have to establish the momentary orbit.

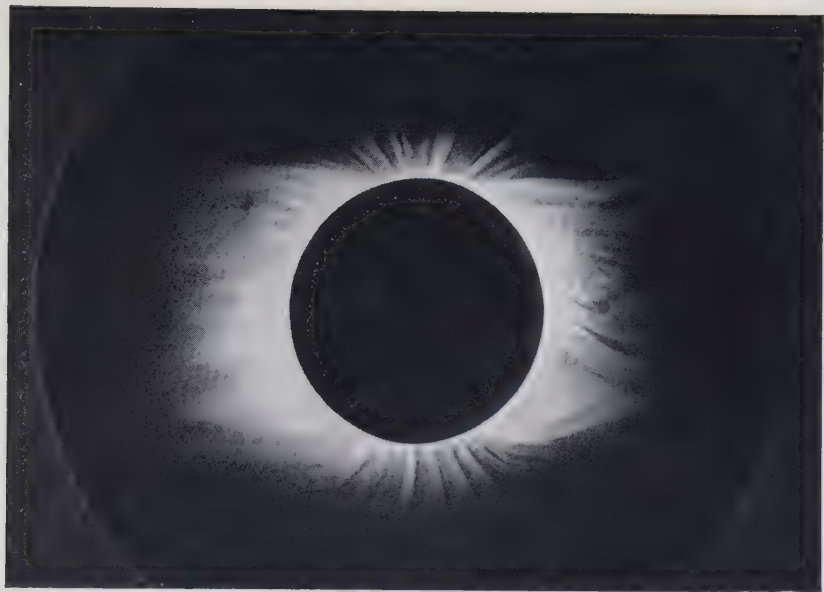


PLATE X. Photograph of the eclipsed Sun, showing small Faculae and the Sun's Corona, both of which are invisible except during the total phases of an eclipse of the Sun.

Royal Observatory, Greenwich

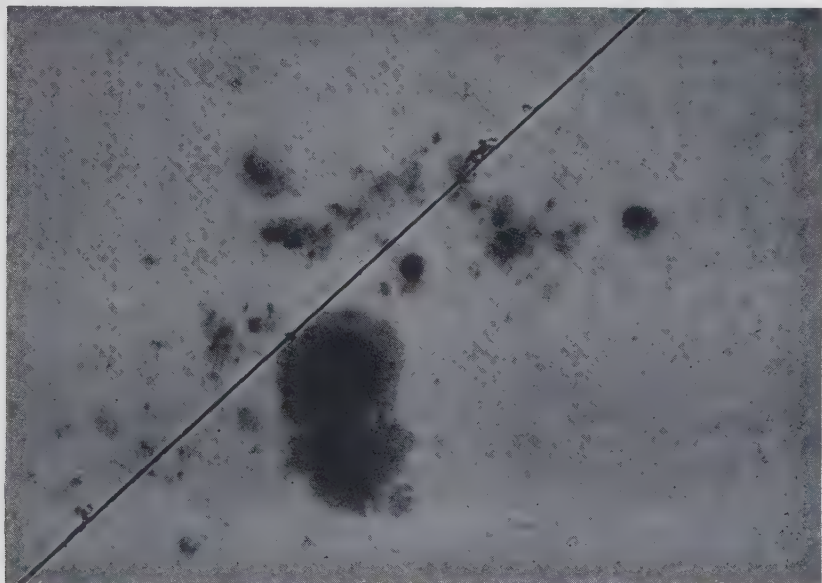


PLATE XI. Part of the Sun's surface with a group of sunspots. The curious 'granulation' of the surface is also visible.

Royal Observatory, Greenwich



PLATE XII. The Moon, seven and a half days old. This photograph shows many of the Moon's features, but even a small telescope reveals considerably more detail.

Paris Observatory

As with the planets, the approximate position of the Moon is found by considering her movement to be uniform, covering a little over 13 degrees per day, and reckoning this movement from an epoch. We thus obtain the Moon's mean position. The fact that her apparent orbit is an ellipse causes her to either be in advance or to be behind that mean position by an amount which is called, again, the equation of the centre. At its maximum this can amount to as much as 6.3 degrees, almost half as much as the average daily motion of the Moon.

The excentricity of the Moon's orbit varies slightly, and this causes an inequality, called the *evection*, which can amount to 1.3 degrees, and yet another disturbance is caused by the fact that the distance of the Earth-Moon System from the Sun changes throughout the year. The annual equation, amounting to 0.2 degrees at maximum, allows for this.

The last correction to be applied to the Moon's mean position which we shall discuss here is the *variation*, amounting to 0.6 degrees. This is caused by the fact that the difference between the gravitational forces of the Sun and of the Earth is not constant, as that of the Sun is a little less while the Moon is on the far side of the Earth, and it is greater when the Moon is between the Earth and the Sun.

Without applying these corrections, the position of the Moon, as calculated by the mean movement, may differ by as much as $8\frac{1}{2}$ degrees from the actual position, and it is therefore very necessary to correct the Moon's mean longitude by these equations.

CALCULATING THE MOON'S POSITION

For the purposes of navigators, the positions of the Moon throughout the year are tabulated in the Nautical Almanac, and the required accuracy makes it necessary to apply 1,500 corrections to the Moon's mean longitude, which is calculated for midnight and noon of every day. The graphs at the end of this chapter allow for only four of these, and consequently we must expect our calculations to have a slight error at times, which may, in extreme cases, amount to 0.18 degree. As it is not possible to read the values from the graphs with an accuracy greater than 0.05 degree, we must expect that our calculations, taking this into account, may be nearly $\frac{1}{4}$ degree in error, and the times which we derive from the Moon's position, may therefore, be a little over 20 minutes out, although usually the error will be found to be much smaller.

Rather than giving long explanations of the graphs, let us make an

TIME, etc.	SUN		MOON		NODE
	LONGITUDE	PERIGEE	LONGITUDE	PERIGEE	
1950:	279°16	282°2	51°23	208°9	12°1
5 years:	358°74		286°90	203°2	96°6
1 year:	359°75		129°38	40°6	19°3
2 leap days:	1°97		26°35	0°2	0°1
November:	299°64		45°63	33°8	16°1
10 days:	9°86		131°76	1°1	0°5
8 days:	7°88		105°41	0°9	0°4
4 hours:	0°17		2°20		133°0
18 Nov. 1956, 04°00 hrs. G.M.T.:	$S = 237°17$	$p = 282°2$ $S - p = a$	$M = 58°86$	$P = 128°2$ $M - P = A$	$N = 239°1$
Eq. of the centre	$- 1°33$ $S' = 235°84$	$a = 315°0$		$A = 290°5$	
$M =$	58°86				
$S' =$	235°84				
$M - S' =$	183°02				
$2(M - S') =$	366°04				
$A =$	290°5				
$2(M - S') - A =$	75°5	Evection:	1°29	1°3	
$a =$	315°0	Annual Eq.:	0°13	0°1	0°1
				0°3	
		Eq. Cen tre:	- 5°68	$A' = 292°2$	
$M' =$	54°60	$M' = 54°60$			
$S' =$	235°84				
$M' - S' =$	178°76	Variation:	- 0°04		
		$M'' = 54°56$			$N' = 239°2$
$M'' =$	54°56				
$N' =$	239°2				
$M'' - N' =$	175°4	Reduction:	0°02	Mean Latitude:	0°42
		Ecl. Long.:	54°58°		
$M'' =$	54°56				
$S' =$	235°84				
$M'' - S' =$	178°72				
$2(M'' - S') =$	357°44				
$(M'' - N') =$	175°4				
$2(M'' - N') - (M'' - N') =$	182°0			Correction:	-0°01
				Latitude:	0°41°
Moon's Parallax ρ	=	0°97°	Moon's hourly motion in Long.: 0°57°		
Sun's Semi-diameter σ	=	0°27°	Moon's hourly motion in Lat.: -0°05°		
Moon's Semi-diameter s	=	0°27°			

Fig. 61. Position of the Moon on 18 November 1956, 0·400 hrs. G.M.T.

actual calculation, say, that of the Moon's position on 18 November 1956, at 04.00 hrs. G.M.T.

The position of the Sun enters into our calculations, and for this purpose it is best to consider the Sun to move, like the Moon, around the Earth, rather than calculate the Earth's actual position, and then find that of the Sun by adding 180 degrees to the calculated longitude.

Finding the mean longitudes is very much the same as with the planets, and we have to add up figures for the Sun's mean longitude, S , the longitude of his perigee, p , which, however, needs no addition for the years, months, etc., as its movement becomes noticeable only after very long periods; then the Moon's mean longitude, M , the longitude of the Moon's perigee, P , and finally the longitude of the node, N . With the last, however, we must remember that the nodes retrograde, and the figures for the years, months, etc., alone are added together, omitting the longitude of the node at the epoch. The result is then subtracted from the longitude at the epoch, and in our case we have to add 360° first, before we can subtract the figures.

From these mean values for 18 November 1956, 04.00 hrs. G.M.T., we calculate a , the Sun's *anomaly*, and A , the Moon's *anomaly*. These are the angular distances of the Sun and the Moon from the perigees of their orbits.

We require these quantities for the determination of the equations of the centre of the two, and we should have employed a similar quantity when we calculated the positions of the planets. Their perihelia, however, are fixed in space, and the magnitude of the equation of the centre could be referred to the ecliptic longitude. Here, however, we cannot do this, and the anomalies must actually enter our calculations.

The first correction to be applied is the Sun's equation of the centre, the value of which is found from the appropriate graph, and it depends on the Sun's mean anomaly, a . By adding or subtracting this quantity, we obtain the Sun's *corrected longitude*, S' .

Next we calculate the value of the expression $2(M-S')-A$, as indicated in Fig. 61, and with this we enter the graph for the evection, which is the first correction to be applied to both the Moon's longitude and her anomaly.

The annual equation, the second correction of the Moon's longitude and anomaly, is found by entering the graph with the value of a , the Sun's mean anomaly.

The next correction is applied to the Moon's anomaly only, and

again we need the Sun's mean anomaly to enter the graph. The three corrections to the Moon's anomaly are now added to it (those which are negative are, of course, subtracted), and we thus obtain A' , the Moon's corrected anomaly.

With A' we enter the graph for the third correction of the Moon's longitude, which is the equation of the centre. Now we can add these three corrections to the mean longitude of the Moon, and obtain M' , the corrected Longitude of the Moon.

The graph for the variation is entered with the value of the expression $M' - S'$, and when this correction has been applied to the corrected longitude of the Moon, the result is the true longitude, measured along the orbit, and denoted by M'' .

Owing to the inclination of the Moon's orbit to the ecliptic, M'' is not identical with the ecliptic longitude, and in order to find this we have to apply the *reduction* to the ecliptic, which gives us the amount to be added to the orbital longitude (or to be subtracted from it) in order to obtain ecliptic longitude.

The value of this depends on the Moon's angular distance from the node, and in order to find this we first have to correct the longitude of the node, and obtain N' , and we can then calculate $M'' - N'$, from which we find the reduction, and also the Moon's mean latitude. M'' plus or minus the reduction gives us the ecliptic longitude of the Moon, and all that remains to be done is to correct the latitude.

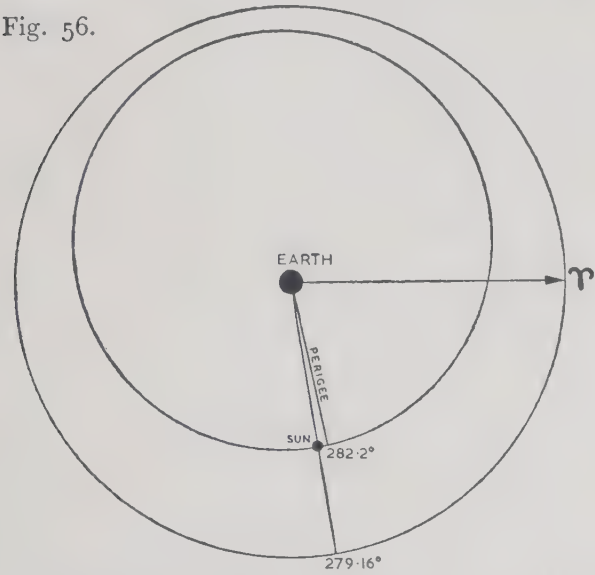
The value with which we have to enter the graph is found by calculating $2(M'' - S') - (M'' - N')$, and applying this to the mean latitude. Our result is the true latitude of the Moon, and we can now convert the ecliptic co-ordinates into the equatorial ones, that is, express the Moon's position in terms of R.A. and decl. Her position can now, as we have done with the stars, be entered in a star map, or on our astrolabe. This is of little value, however, as the Moon's position alters appreciably during one night, but the value of these calculations is not diminished, as we shall see in the next chapter.

The value of $M'' - S'$, in our example, was found to be 178.72° , which is very nearly 180° . The Moon, therefore, has almost reached the point of opposition to the Sun, and the exact moment of Full Moon should occur about $2\frac{1}{2}$ hours after the time for which the position has been calculated. Incidentally, it is also the time of an eclipse of the Moon, but this is a problem which we shall discuss later, when we have learnt how to 'spot' likely times of eclipses.

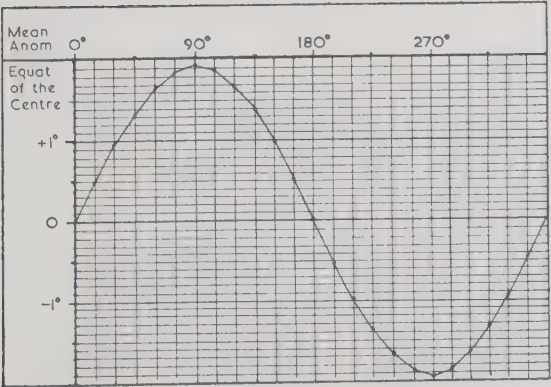
S U N	
Epoch: 1950, 0 January, 0 hrs. G.M.T.	
Daily Motion:	0.9856°
2 days:	1.97
3	2.96
4	3.94
5	4.93
6	5.91
7	6.90
8	7.88
9	8.87
10	9.86

Add for		Add for	
1 year:	359.75°	January	0.00°
2 years:	359.49	February	30.56
3	359.24	March	58.16
4	358.99	April	88.72
5	358.74	May	118.29
10	357.47	June	148.84
20	354.95	July	178.41
30	352.42	August	208.96
40	349.89	September	239.52
50	347.36	October	269.09
Add one day for each leap year since 1950		November	299.64
		December	329.21

Fig. 56.



Add for	
1 hour:	0.04°
2 hours:	0.09
3	0.13
4	0.17
5	0.20
6	0.24
7	0.28
8	0.32
9	0.37
10	0.42
11	0.45
12	0.49
13	0.53
14	0.58
15	0.62
16	0.66
17	0.69
18	0.73
19	0.77
20	0.81
21	0.85
22	0.90
23	0.94



Notes	
Mean Semi-Diameter 0.27°	

MOON

Epoch: 1950, 0 January, 0 hrs. G.M.T.

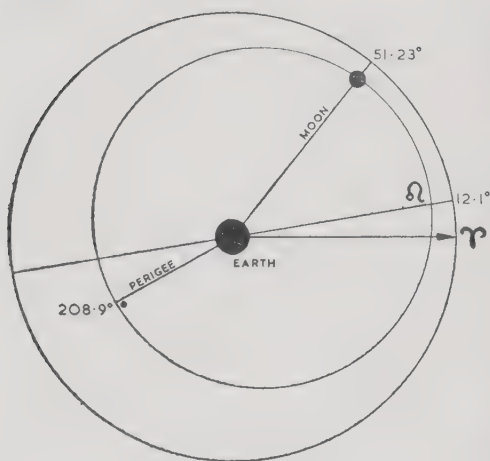
Add for	Long.	Perigee	Node
1 year:	129°38'	40°6'	19°3'
2 years:	258°76'	81°3'	38°7'
3	28°14'	121°9'	58°0'
4	157°52'	162°6'	77°3'
5	286°90'	203°2'	96°6'
10	213°8'	46°5'	193°3'
20	67°6'	92°9'	26°6'
30	281°4'	139°4'	219°8'
40	135°2'	185°9'	53°1'
50	349°0'	232°3'	246°4'

Add one day for each leap year since 1950

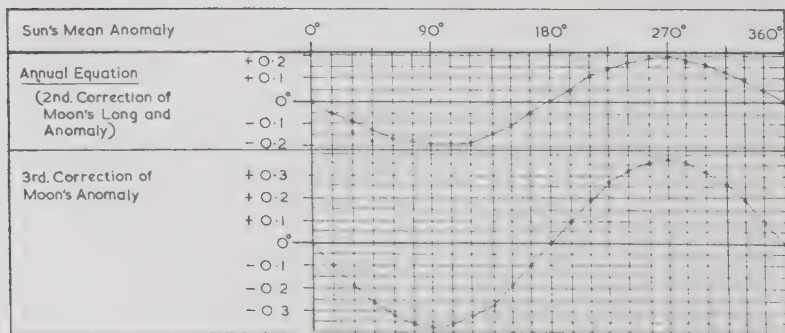
Add for	Long.	Perig.	Node
1 day:	13°18'	0°1'	0°1'
2 days:	26°35'	0°2'	0°1'
3	39°53'	0°3'	0°2'
4	52°70'	0°4'	0°2'
5	65°88'	0°6'	0°3'
6	79°06'	0°7'	0°3'
7	92°23'	0°8'	0°4'
8	105°41'	0°9'	0°4'
9	118°59'	1°0'	0°5'
10	131°76'	1°1'	0°5'

Add for	Long.	Perigee	Node
Jan.	0°00'	0°0'	0°0'
Feb.	48°47'	3°4'	1°6'
Mar.	57°41'	6°5'	3°1'
Apr.	105°88'	10°0'	4°7'
May	141°17'	13°3'	6°3'
June	189°64'	16°8'	8°0'
July	224°93'	20°1'	9°6'
Aug.	273°39'	23°5'	11°2'
Sep.	321°87'	27°1'	12°8'
Oct.	357°16'	30°4'	14°4'
Nov.	45°63'	33°8'	16°1'
Dec.	80°92'	37°2'	17°6'

Fig. 57.



Add for	Long.	Add for	Long.
1 hour:	0°55'	13 hours:	7°14'
2 hours:	1°10'	14	7°69'
3	1°65'	15	8°24'
4	2°20'	16	8°78'
5	2°75'	17	9°33'
6	3°30'	18	9°88'
7	3°84'	19	10°43'
8	4°40'	20	10°98'
9	4°94'	21	11°53'
10	5°49'	22	12°08'
11	6°04'	23	12°63'
12	6°59'	24	13°18'



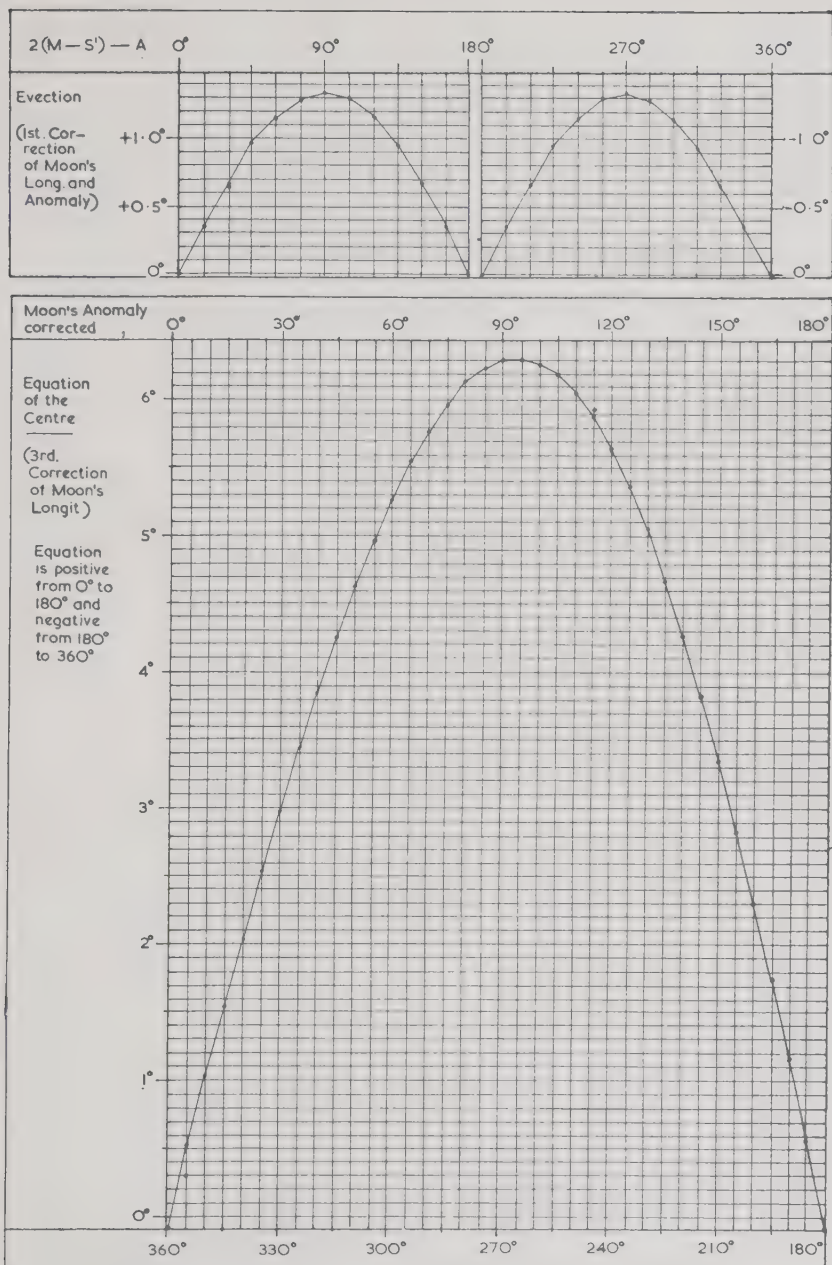


Fig. 58. Evection and equation of the centre

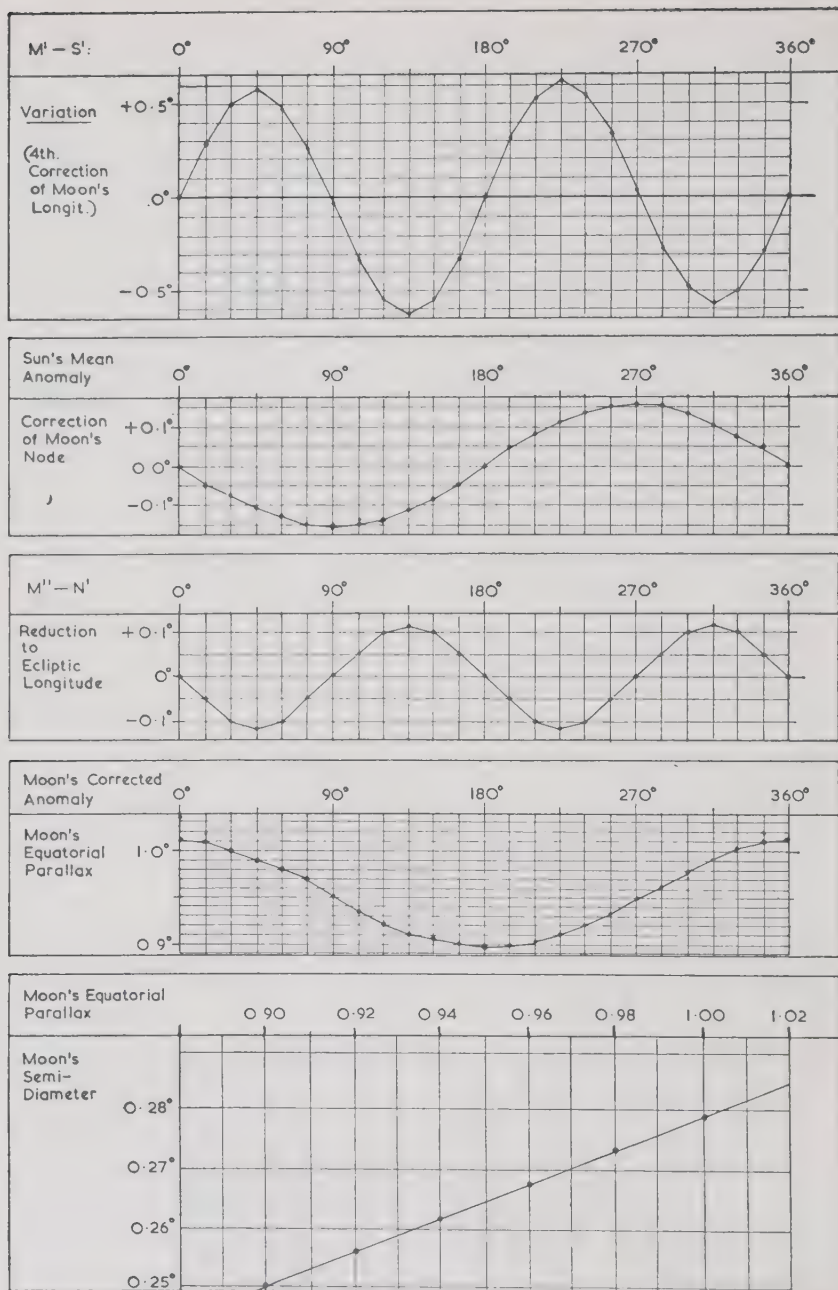


Fig. 59. Variation, reduction, semi-diameter, etc.

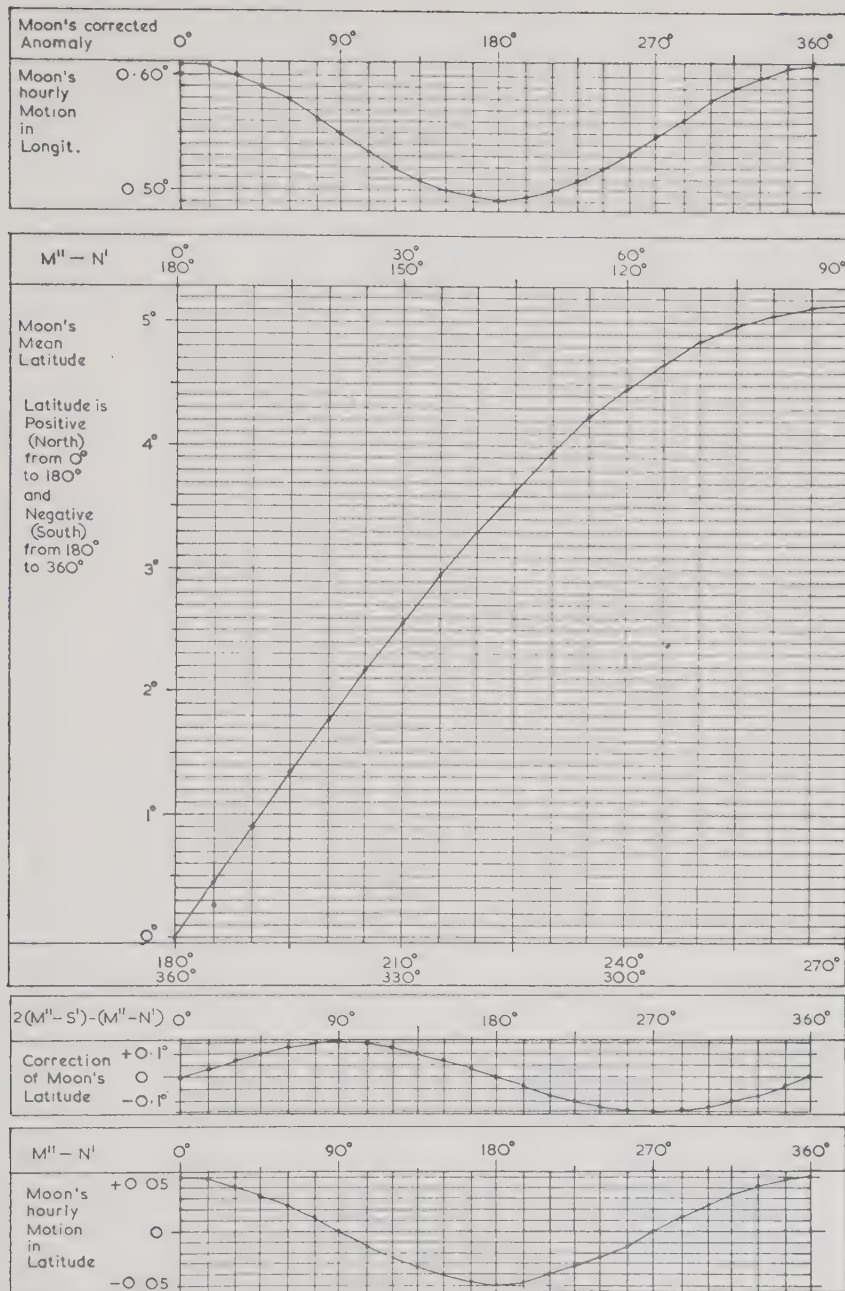


Fig. 60. Latitude and hourly motion

Our Astronomical Calendar

THE PURPOSE of an astronomical calendar is to show the phenomena of the planets, the Moon and the Sun throughout the year and to give their places in the sky for every day. The accuracy required by navigators makes it necessary to produce tables like those of the Nautical Almanac, with over 500 pages of figures, but for our purposes something much simpler will suffice, something which indicates the happenings in the sky at a glance without having to go through hundreds of pages.

With our calculations of the positions of the planets and of the Moon we are able to produce such a calendar ourselves, an occupation which is admirably suited for a wet winter's evening, when the actual sky is hidden behind clouds. Such a calendar, computed for the year 1955, is shown in Fig. 62, and printed at the end of this book we find a chart which contains only those parts of the calendar which are the same every year, and we can enter the additional curves as determined from our calculations. It is not very difficult to make these additions, although quite a few hours will have to be spent on the making of the calendar.

Along the two sides of the calendar are the dates from January to December, and along the bottom we find the hours of rectascension. On 1 January, the Sun has the R.A. of 18 hrs., 40 mins., and this is the starting-point of the curve which represents the path of the Sun throughout the year. In the centre of the calendar we find the equator and the ecliptic, with the main stars of the zodiacal constellations. If we want to know the position of the Sun among the stars, we follow the line from the date in question across the chart until we come to the point where this line crosses the curve of the Sun. From this point we

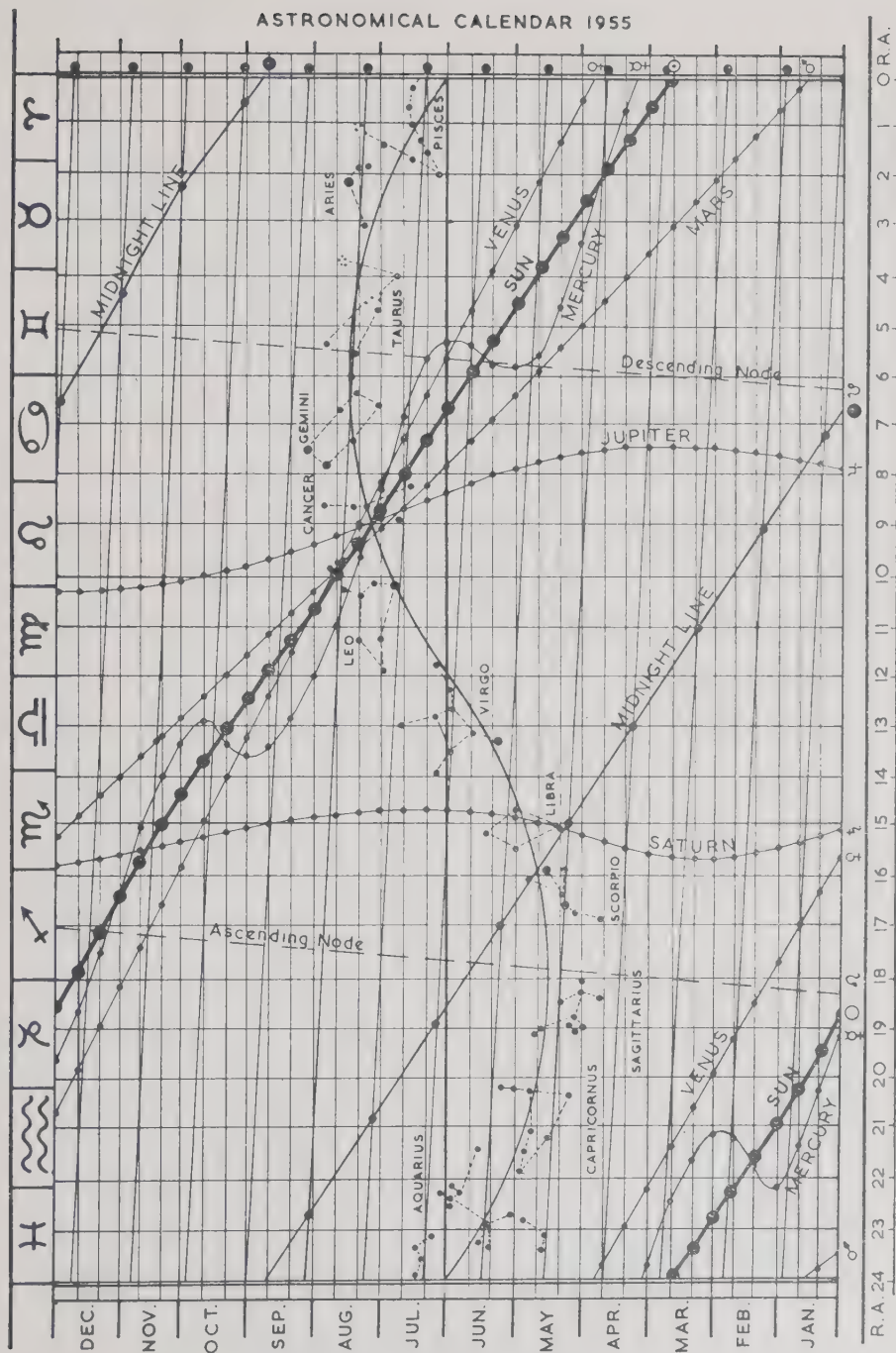


Fig. 62. Astronomical calendar, 1955

go straight up or down, and the point of the ecliptic thus reached is the position of the Sun on that day.

The positions of the planets are added to our chart in a similar manner. It is necessary to calculate their rectascensions for only one day in every month, preferably the 1st, and then connecting these points by a smooth curve. Only in the case of Mercury and Venus will it be found necessary to calculate additional points of their curves, at the times when they are retrograde, that is, when they move from left to right across the sky. But even at these times, one position for every tenth day is sufficient to draw the curve.

The faint lines running slantwise across the chart in Fig. 62 represent the path of the Moon, and these need not be calculated at all; we only have to find the first date in the year on which the R.A. of the Moon is 0 hrs., and from that date, on the right-hand margin, draw a line to the date on the left-hand margin which is 27.3 days ahead of the first. The next line starts again from the right-hand side of the chart, and from the date at which the first line ended. In this manner we continue until we reach the top of the calendar. The Moon will then be found to have circled the whole sky a little more than 13 times during the year.

The positions of the two nodes of the Moon's orbit are also marked, and these retrograde 19.3 degrees per year. Ascending and descending nodes are exactly 180 degrees, or 12 hours of rectascension apart.

Finally, there is the *midnight line*, which is 180 degrees or 12 hours apart from the line representing the path of the Sun. This midnight line marks the point of the ecliptic which is due South at midnight on any particular date. These, then, are all the lines which appear in the calendar. Of course, many more lines could be drawn, representing the perigee of the Moon, times of sunrise and sunset and so on, but this all must be left to the user of the calendar.

What are the conclusions which we can draw from studying these lines on the astronomical calendar? Let us consider the one drawn for the year 1955. The lines representing the paths of the Sun and the Moon cross each other in many places, and on the dates on which this occurs, Sun and Moon are in the same place of the sky, and it is, therefore, New Moon. The Moon is then in conjunction with the Sun, that is, they both have the same R.A. A few days later the Moon is, in the sky, to the left of the Sun, and the positions of the lines in our diagram represent the actual conditions in the sky.

When the Moon crosses the midnight line, she is in opposition to the Sun, and it is then Full Moon. If we go from such a point of inter-

section to the left or right margin, we can there read off the date of the Full Moon.

It is always worth while to make more detailed calculations for those dates when the Moon crosses the line of one of the planets, as it occasionally happens that the Moon actually occults a planet, that is, passes right in front of it, and the planet is then invisible for about one hour. Very often a conjunction between Moon and planet occurs in the vicinity of several bright stars, without an occultation taking place, however, and it is quite interesting to calculate the exact aspect of the sky for that date. It will be found that the graphs and tables which we use for our calculations are surprisingly accurate, which becomes evident when we enter the calculated positions of the Moon and planet in a star map and afterwards, on the day in question, compare it with the actual aspect of the sky.

Mercury and Venus are morning stars when their curves are to the right of the Sun, and they are evening stars when they are to the left. Mercury, however, is not always visible at the times of its elongations, as the planet may be too low in the sky, and comparing the relative positions of Sun and Mercury on the ecliptic soon tells us whether the planet should be high up in the sky, as it is when its position is on a part of the ecliptic which is above that in which the Sun is situated, or whether it is low down, near the horizon, and therefore in all likelihood invisible.

Mars, Jupiter, Saturn and Uranus are nearest to the Earth, and therefore at their brightest when they are in opposition to the Sun. This is indicated by the points where their curves cross the midnight line. We also notice that this is also the time at which these planets become retrograde, as the Earth is then overtaking them.

Two planets in conjunction are always a beautiful sight, but such occasions are often spoilt by the fact that this occurs in the lower part of the ecliptic, which is never very well seen from our latitude. As the brightest stars in the vicinity of the ecliptic are marked in the calendar, it is not even necessary to consult a star map in order to distinguish the planets from the stars if such question ever arises.

The two lines of the nodes of the Moon's orbit are important for the calculation of eclipses of the Sun or of the Moon. Owing to the inclination of the Moon's orbit relative to the plane of the ecliptic, she usually passes above or below the Earth's shadow at the times of Full Moon, and the Moon's shadow at New Moon passes either above or below the Earth.

Twice a year, however, it happens that the line connecting the two

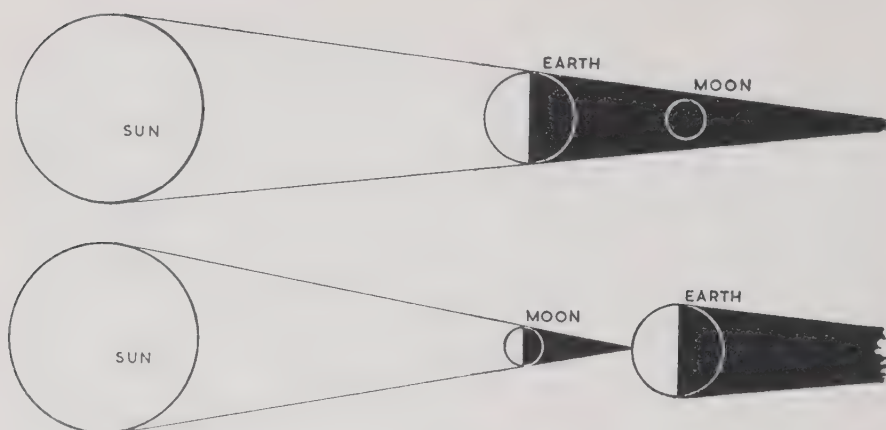


Fig. 63. Eclipses of the Sun and Moon

nodes of the Moon's orbit points roughly at the Sun (see Fig. 54), and then eclipses either of the Sun or of the Moon are possible.

In our calendar these conditions are indicated by the fact that the curve of the Moon crosses either that of the Sun or the midnight line at a point which is very near to one of the lines of the nodes. These three curves then form a small triangle on the chart, and the smaller this is, the more likely is an eclipse to happen.

In 1955, there were three, an eclipse of the Sun on 20 June, a partial eclipse of the Moon on 29 November, and another eclipse of the Sun on 14 December. In each case we see that the triangle is extremely small; in fact, on 20 June it almost disappears altogether.

The shadows of the Earth and the Moon have the shape of a cone, and this is called the *umbra*, into which no sunlight at all can penetrate. The umbra is surrounded by the *penumbra*, and an observer situated in this would see the Sun partially eclipsed.

The point of the cone of the Moon's umbra is just about far enough behind the Moon to reach the Earth, and eclipses of the Sun are therefore observed only in a very small part of the Earth's surface. The shadow traces out a narrow strip on the Earth, owing to the Moon's movement and the Earth's rotation. In this strip an eclipse of the Sun can, at maximum, last for 7 minutes as observed from any one point, but usually this time is much shorter, as the Moon's distance from the Earth varies, and the diameter of her shadow which falls on

the Earth is much smaller when the Moon is farther away. Sometimes it is so far away that the tip of the cone of the umbra does not reach the Earth at all, and an observer can see the dark Moon in the sky, surrounded by a narrow ring of light—the edge of the Sun. Such an eclipse is called an *annular* one, thus distinguishing it from a *total* eclipse.

The zone of totality is, on either side, skirted by a much wider zone in which the Sun appears partially eclipsed, but this zone never covers the whole of the Earth's surface. For this reason, eclipses of the Sun are comparatively rare, compared with those of the Moon, although actually many more eclipses of the Sun occur than do eclipses of the Moon. But the latter are always visible from the whole of the Earth's hemisphere in which the Moon is above the horizon, while the visibility of the former is restricted to a very small part of the Earth.

The prediction of eclipses is by no means an achievement of recent times. The Chinese knew many thousand years ago that eclipses recur in the same order after 18 years and 11 days, or 18 years and 10 days if five leap years intervene.

The Moon makes one revolution with respect to the nodes of her orbit in 27·21 days, and the Sun makes one revolution in 346·62 days. After 18 years and 11 days—the ancient Chaldeans called this period one *Saros*—the Sun has completed 19 revolutions with respect to the Moon's nodes, and the Moon has completed 242. The relative positions of the two bodies are almost the same, and for this reason an eclipse on any date recurs after this interval.

As the other conditions of such an eclipse do not recur after the same interval, this rule is not valid for an indefinite time, and not every eclipse can be predicted with the *Saros*.

ECLIPSES

For the accurate prediction of an eclipse we have to resort to some calculations, as our astronomical calendar only gives the approximate date.

In the last chapter we have calculated the position of the Moon, and we have to do this again for any likely eclipse, in exactly the same manner. By estimation or guesswork we try to find the time at which the Moon's distance from either the Earth's shadow (Lunar Eclipse) or from the Sun (Solar Eclipse) is about one degree, that is, the value of the expression $M'' - S'$ in our calculations becomes a little less than 180°

in the case of an eclipse of the Moon, or a little less than 360° in the case of an eclipse of the Sun.

This means, of course, calculating the Moon's longitude, and, by applying the Moon's hourly motion in longitude, finding the time for which we have to do the next calculation, until we have made one like that in Fig. 61, in which $M'' - S'$ has a value of about 179° or 359° .

For the calculation of an eclipse of the Moon it is, of course, necessary to know the diameter of the Earth's shadow at the distance of the Moon, and also whether or not the Moon passes centrally through it or more towards the upper or lower boundaries of the shadow.

The semi-diameter, or radius, of the Earth's shadow at the distance of the Moon is the distance $F-G$ in Fig. 64, and for an observer situated in the point A , this distance subtends an angle $F-A-G$, which we must try to express in terms of other, known, quantities.

Three such quantities go into the calculation. The angle $A-S-C$, which is the semi-diameter of the Earth as seen from the Sun, and this angle is called the *Sun's horizontal parallax* (π). The angle $A-G-C$, which is the angle subtended by the Earth's semi-diameter as seen from the Moon, and this is the *Moon's horizontal parallax* (ρ), and finally the angle $B-C-S$, which we call the *Sun's semi-diameter* (σ).

If we draw a line parallel to $C-G$ through A , we obtain the point E , and for an observer at the centre of the Earth, the angle $G-C-E$ is equal to the Moon's horizontal parallax. From A , the distance $E-G$ subtends exactly the same angle, and as the angle $D-A-E$ is equal to the angle $A-S-C$, the angle $D-A-G$ is equal to the Sun's and the Moon's horizontal parallaxes combined.

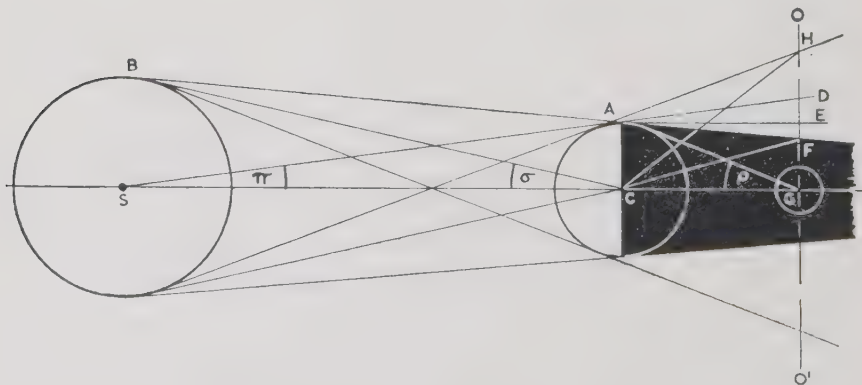


Fig. 64. The diameter of the Earth's shadow

The angles $H-A-D$ and $D-A-F$ are, of course, equal to the Sun's semi-diameter, and we obtain for the diameter of the Earth's shadow at the distance of the Moon the value : Sun's parallax plus Moon's parallax minus Sun's semi-diameter. For the diameter of the penumbra we have to add all three quantities, but as penumbral eclipses of the Moon cannot be observed without fairly expensive instruments, it is of no practical value to us.

The semi-diameter of the Sun is 0.27° on the average, and the differences due to the excentricity of the Earth's orbit are so small that we can neglect them and consider this value as constant.

The value of the Sun's horizontal parallax is about $1/500$ of a degree, and this is so small that we can safely leave it out of our calculations altogether, as it makes near to no difference at all.

The Moon's horizontal parallax, however, changes appreciably, and its value at any time can be taken from one of our graphs, and from the Moon's parallax we determine, with the aid of yet another graph, the Moon's semi-diameter, which we shall need presently.

With an accuracy which is sufficient for our purposes, we can thus reduce the expression for the diameter of the Earth's shadow at the distance of the Moon to the simple formula :

$$\text{Diameter of Shadow} = \text{Moon's Parallax minus } 0.27^\circ$$

Now we are all set for calculating the circumstances of our eclipse. First, we draw a straight line, which is to represent the ecliptic, and somewhere on it we mark off a distance of one inch, or some other suitable distance, which is to be the distance of one degree in our diagram, as measured along either the ecliptic or along the Moon's orbit, or along one of the hour circles of that part of the celestial sphere which our diagram represents.

The semi-diameter of the Earth's shadow is in our example 0.97° minus $0.27^\circ = 0.70^\circ$, and we can draw a circle of that radius, centred somewhere on the ecliptic. We may also draw another one, with the same centre, but of 1.24° radius, representing the semi-diameter of the penumbra.

The value of $M''-S'$ was found as 178.72 degrees, which means that the Moon has to travel another 1.28 degrees before she reaches the same longitude as the centre of the shadow. We can therefore mark the point A 1.28 degrees to the right of the centre of the shadow, and at a latitude of 0.41° North, which is then the centre of the Moon at the time for which our calculations have been made. Around this point

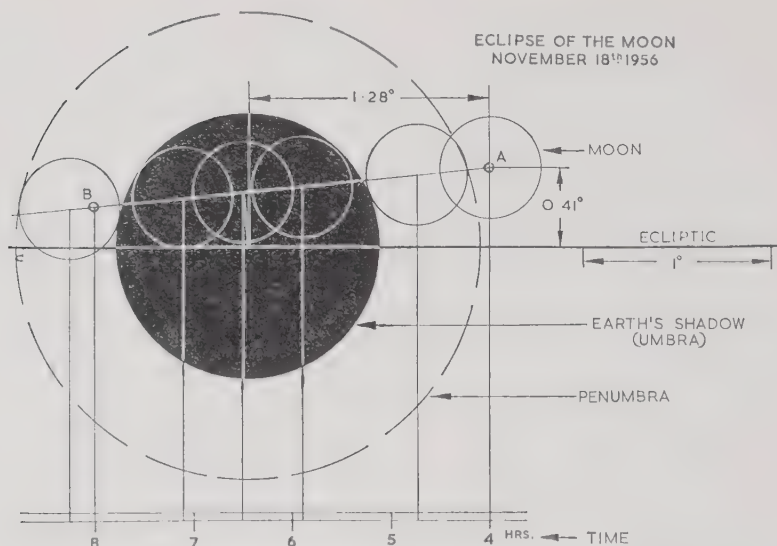


Fig. 65. Eclipse of the Moon, 18 November 1956

we draw a circle, representing the Moon, with a radius of 0.27° , the value of which we have found from our last graph.

Both Moon and shadow travel towards the left in our diagram, the Moon at the rate of 0.57° per hour, and the shadow, like the Sun, at 0.04° per hour.

We know, therefore, that the Moon will approach the shadow at the rate of 0.57 minus $0.04 = 0.53^\circ$ per hour, and from the first position of the Moon, we can mark off towards the left equal spaces of 0.53° , indicating the Moon's position relative to the shadow one, two, three, and so on, hours after the time which we first calculated.

After four hours, however, the Moon has also travelled in latitude, and, as the hourly motion in latitude is negative, she will then have reached the latitude 0.21° . Now we can plot point *B*, which is the Moon's position relative to the shadow at 8 A.M. The line connecting the two represents the Moon's path during the interval of four hours.

We can now draw circles, with radii equal to the Moon's semi-diameter, which touch the Earth's shadow from the outside and from the inside, and which have their centres somewhere along the path of the Moon.

These circles indicate the positions of the Moon at the times when she makes her first contact with the shadow of the Earth, and the last contact, and also the beginning and the end of the total phase. Lines drawn from the centres of these circles, at right angles to the ecliptic, will meet our time-scale underneath in those points which indicate the times of these phenomena.

The time of the middle of the eclipse is found by drawing a line through the centre of the shadow, at right angles to the path of the Moon, and then drawing another line, as before, from the point where it intersects the path of the Moon to the time-scale below. In our example mid-eclipse is indicated at 6.35 A.M. on 18 November 1956.

But, as we have seen already, these figures are not 100 per cent. correct, although usually we will find that the maximum error of $\frac{1}{4}$ degree or 20 minutes is considerably above the actual error which we encounter. Here we will find that our calculations indicate the times of the different phenomena 12 minutes earlier than the actual times of their occurrence. Considering the comparative simplicity of our method, this result must be called quite good, and if we are not satisfied with it, we can always look up the exact times in the Nautical Almanac, the computers of which have applied 1,500 corrections to the Moon's longitude, but still they cannot claim that their figures are absolutely correct either.

For an eclipse to occur it is not necessary that the Moon is exactly in the node of her orbit at the time of opposition or conjunction. In fact, the distance between Moon and node can be as much as 16 degrees, and an eclipse of the Sun is still possible under otherwise favourable conditions. For this reason we find that eclipses do not occur separately, but there are usually two or three at intervals of a fortnight. The distance of the Moon from the node does not alter sufficiently during that period to make an eclipse impossible, and we often find that an eclipse of the Moon is preceded as well as followed by eclipses of the Sun.

The limit for lunar eclipses is much less, and an eclipse of the Sun can occur without any accompanying eclipses of the Moon, but a lunar eclipse is always either preceded or followed by a solar one, and sometimes both.

After a spell of eclipses, the shadows of the Earth and the Moon produce no further ones, as the Moon's latitude has become too great at the times of Full and New Moons, until, half a year later, the Sun has arrived at the other node of the Moon's orbit, and another series of eclipses becomes possible.

In any year, therefore, we find that there must be at least two eclipses, which are then both of the Sun, and there may be as many as seven, five of the Sun and two of the Moon. There can never be more than three lunar eclipses during any one year.

14

The Telescope

IT is a very common, but erroneous opinion that astronomical observations require powerful telescopes. There are hundreds of astronomers who hardly ever use anything more powerful than binoculars, although their instruments may be more suited to their purposes than these.

A surprising number of interesting observations can be made with opera-glasses or field-glasses, and it is only necessary to hold them steady enough to make it possible to see fine detail. Usually this is not always possible, and the owners of binoculars will find it well worth their while to make a little gadget which makes really useful observations possible.

MOUNTING BINOCULARS

A gadget for this purpose is shown in Fig. 66. A small piece of hard-wood has a hole drilled in it, which is just large enough to make it possible to screw it on the thread of a photographic tripod, preferably one with a ball-joint. On the top of this piece we screw a flat piece of cardboard, a flat piece of felt, and on top of these felt and cardboard again and a strip of metal, all of which are of the shape shown in the figure.

Before actually screwing these down, the axle of the binoculars is placed in the loop, and then the two screws are inserted and tightened. This arrangement prevents any possible damage to the paintwork of the glasses, and holds them steady enough for our observations.

Of course, anyone who takes a more than passing interest in astronomy will consider this arrangement as a mere stand-by, and will long for a proper telescope.

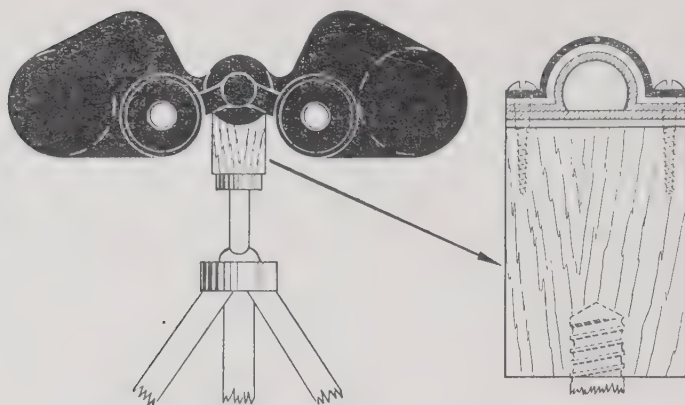


Fig. 66. Mounting binoculars

Unfortunately, these are rather expensive, even if bought second-hand, but the construction of a useful instrument is so simple that practically everyone can make one, and the cost is really negligible. In fact, the author has, for the past twenty years, used a telescope which originally cost no more than 3s. 6d., the price of three lenses. In the course of the years, this has been greatly improved and by now it is quite a formidable instrument with many attachments, yet the total cost of it is still under £10. Although this is quite a small telescope, its possibilities have not yet been exhausted, even after all these years.

A SIMPLE TELESCOPE

Strange as it may seem, the magnification of the object to be viewed is the least important function of the telescope. It is quite possible to construct one which magnifies 100 times and yet does not show any more detail than can be seen with the naked eye. On the other hand, it is possible to construct a telescope which does not magnify at all, and yet is a very useful instrument. The quality of a telescope, it seems, depends not on its power of magnification but on something else.

The deciding factor in this case is the diameter of the object lens, which is that lens in the telescope which is turned towards the object to be viewed.

The diameter of the lens in the human eye is about $\frac{1}{8}$ of an inch, and under good conditions it is possible to see stars of the 6th magnitude. A telescope with an object glass of 1-inch diameter will show stars of mag. 8.5, and its power of definition is such that it will show, as two separate points of light, two stars which are no more than 4.5" apart. Doubling the diameter of the object lens adds another 1.5 magnitudes to the lowest one visible, and halves the distance between double stars which it is capable of separating. A 2-inch telescope, therefore, shows stars of the 10th magnitude, and separates stars which are 2.25" apart.

For our purposes, a telescope with an aperture of one inch is quite sufficient, and its construction should not present any real difficulties. First of all we have to obtain three lenses, and almost any optician can supply these. The object lens should have a diameter of about 2 inches, and a focal length of 36 to 40 inches. The other two lenses are much smaller, one having a focal length of 1 inch, and the other $\frac{1}{2}$ inch.

Before we can start the actual construction, we have to determine the actual focal length of the object glass. This is done by holding the lens in the sunlight, and about three feet underneath a sheet of paper on which the lens will then project an image of the sun. The distance between the two is then altered until the image is of the smallest possible diameter, and in this position we measure the distance between lens and image, which is the focal length.

The tube of our telescope must be about 4 inches shorter than this focal length, and of a diameter about $\frac{1}{8}$ or $\frac{1}{4}$ of an inch larger than that of the object glass. Cardboard tubes of this size are quite easily obtainable, but even better suited to the purpose are the aluminium pipes used by builders for their scaffolding. If this can be found with a suitable diameter, our telescope will be a very sturdy affair, able to stand up to quite a few hard knocks.

Next we cut a strip from a sheet of drawing paper, about three inches wide, and roll and glue it into a tube. The inside diameter of this must be large enough to accommodate the object lens and we have to make its walls thick enough to make the outside diameter such as to make it possible to push this tube into the large aluminium one, without it falling out by itself again. Over one end of this tube we glue further strips of paper, about $\frac{1}{2}$ inch wide, until we have made a ring around it which has a thickness of at least $\frac{1}{2}$ inch. This ring makes sure that the tube stays in position after it has been fitted into the larger one.

On the inside of the object lens holder, we glue another strip of

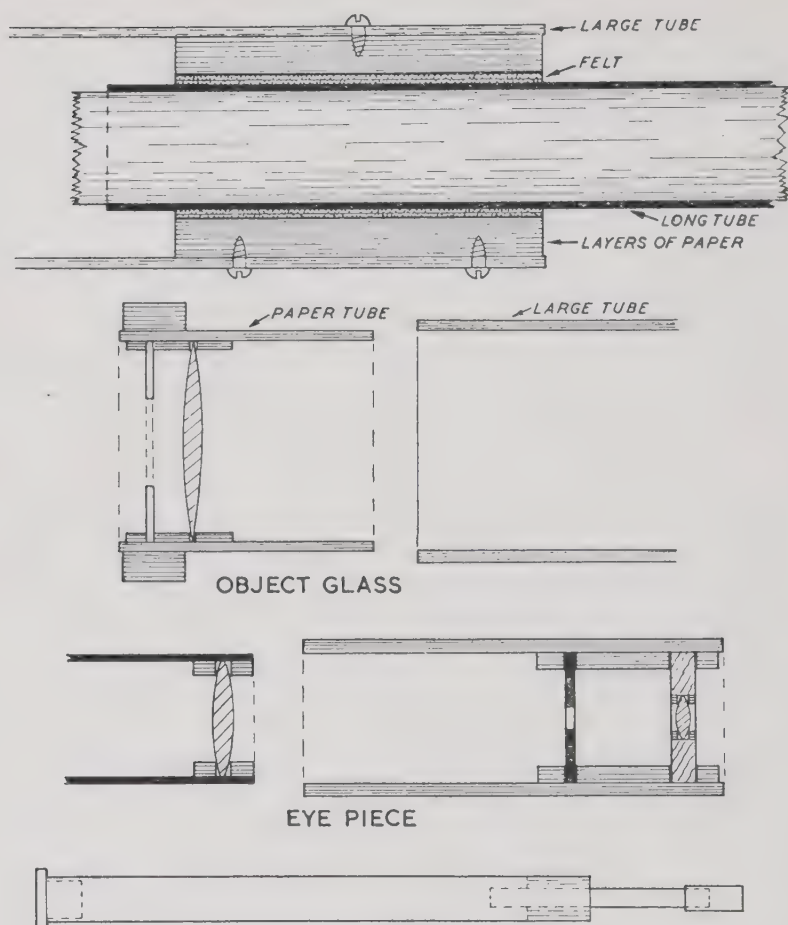


Fig. 67. A simple telescope

paper, several layers thick, place the lens on top of it, and then add another ring of paper-strips, about $\frac{1}{2}$ inch wide. Then comes a circular disk, cut from cardboard, which has a round hole in its centre, the diameter of which should be about one inch. This again is held in position by yet another strip of paper which is glued inside the tube. (See Fig. 67.)

The cardboard disk acts as a stop, which is necessary with a simple lens like this, as, without it, it will not be possible to obtain clear images with the telescope, as the rays of light falling through the outer parts of

the object lens will produce coloured fringes around the images of the stars, and make the telescope practically worthless.

Next, we glue a sheet of drawing paper into a tube about 12 inches long. This is best done by using a broomstick as a former, making sure, however, that the tube does not stick to it.

When this tube is thoroughly dry, we place a piece of felt around it, about 4 inches long, and over this we glue many layers of paper until the packing is thick enough to fit snugly into the aluminium tube, where it can be secured with two or three little screws. The broomstick is best left in the inner tube all the time, making sure that the tube has not become stuck to the felt but easily slides in the packing. The broomstick is then pushed through to the front end of the telescope, where it is held exactly in the centre of the tube by packing some paper around it. In this condition we let the whole assembly dry for a couple of days, avoiding heat, but making sure that plenty of fresh air circulates around the parts which have been glued.

When all is dry, we remove the broomstick, and make sure that the long, inner tube still slides easily in the packing. In the end of this tube we then mount the lens which has a focal length of 1 inch, two narrow strips of paper, glued into a ring several layers thick, holding it in position.

Last of all we make another tube from drawing paper, which must fit snugly over the long, inner one, and this carries at its end the lens with the shortest focal length, and, farther inwards, another stop which has a hole of about $\frac{1}{8}$ of an inch diameter in it. The distance of this stop from the little lens must be such that the edges of the hole appear perfectly sharp when viewed through the lens.

This tube is then pushed over the long one, so as to make the distance between the two little lenses about 1 to $1\frac{1}{2}$ inches. Before the telescope is finally assembled, all the tubes must be blackened inside, which can be done either with Indian ink or by holding them over a smoking flame of oil of turpentine.

THE TRIPOD

The construction of the tripod is sufficiently explained in Fig. 68. Each leg consists of two pieces of deal, 1 inch by 2 inches by 6 feet long. At the lower end, a metal plate is screwed to the wood, which makes the tripod more secure when standing on hard ground.

A circular piece of hardwood, about 6 inches in diameter and 2 inches thick, has three hardwood blocks screwed to it, the dimensions of which are 2 inches by 2 inches by 4 inches, and the legs are screwed

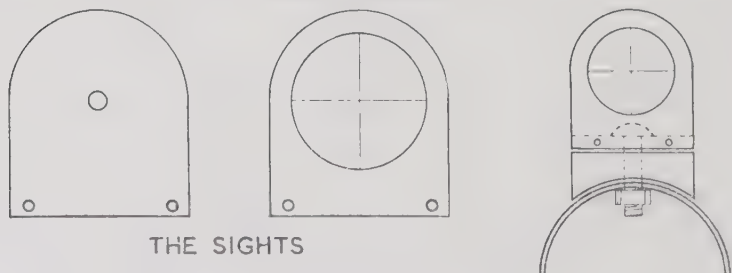
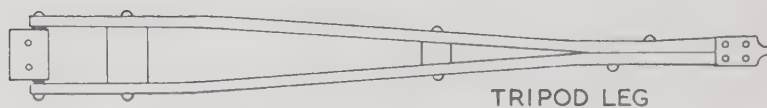
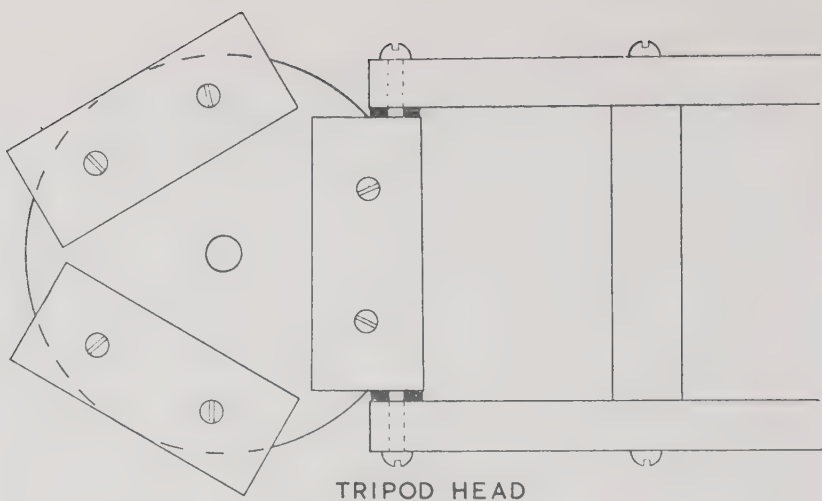


Fig. 68. The tripod and the finder

to these, with a washer placed between the block and each part of the leg. The screws holding these serve as hinges, and if the tripod has been constructed carefully, the circular top-plate is perfectly steady whatever the position of the legs.

The top of the tripod carries the telescope mounting, which is shown in Fig. 69. The telescope itself is secured to its cradle, which is a piece of wood which has a V-shaped groove cut along one of its sides in which the tube rests. This cradle is mounted on a circular piece of wood, which may be graduated for setting the telescope in declination.

The declination axis passes right through these two, and carries weights at its other end, which must accurately counterbalance the telescope.

The bearing of the declination axis revolves around the hour axis, and underneath it is placed a washer. Then follows another circular piece of wood, which, however, is not fixed, and these all are held in position by another block of wood which has a hole drilled through the whole of its length which contains the hour axis. This piece is held at such an angle as to make the inclination of the hour axis equal to the latitude in which the telescope is to be used, that is, the hour axis must, when the telescope is in use, point exactly at the celestial pole.

The disk on the hour axis carries a bearing for a screw with a knurled knob. The friction between this disk and the wood underneath is sufficient to hold it in position, and once the telescope has been directed at a star, it is only necessary to turn this screw in order to make the telescope follow the daily movement of the star as the screw slowly pushes the bearing of the declination axis around.

The setting of the telescope is made a great deal easier if a finder is attached to it, and this is very simple to make. The details of its construction are shown at the bottom of Fig. 68. One of the two sights has a hole of about $\frac{1}{8}$ inch diameter, and the other a 1-inch hole with crosswires mounted inside. The length of the finder should be about 8 inches, and it is fitted to the telescope tube by means of a shaped piece of wood and a screw.

The finder is accurately set by directing the telescope at a distant tower, and bringing one point of it right into the centre of its field of view. The wires in the finder are then bent until they, when seen through the hole at the other end of the finder, cross each other exactly over the spot which is visible in the telescope. The wires can then be fixed in this position by applying a drop of varnish to the centre, and as a final improvement, they may be covered with a little luminous paint.

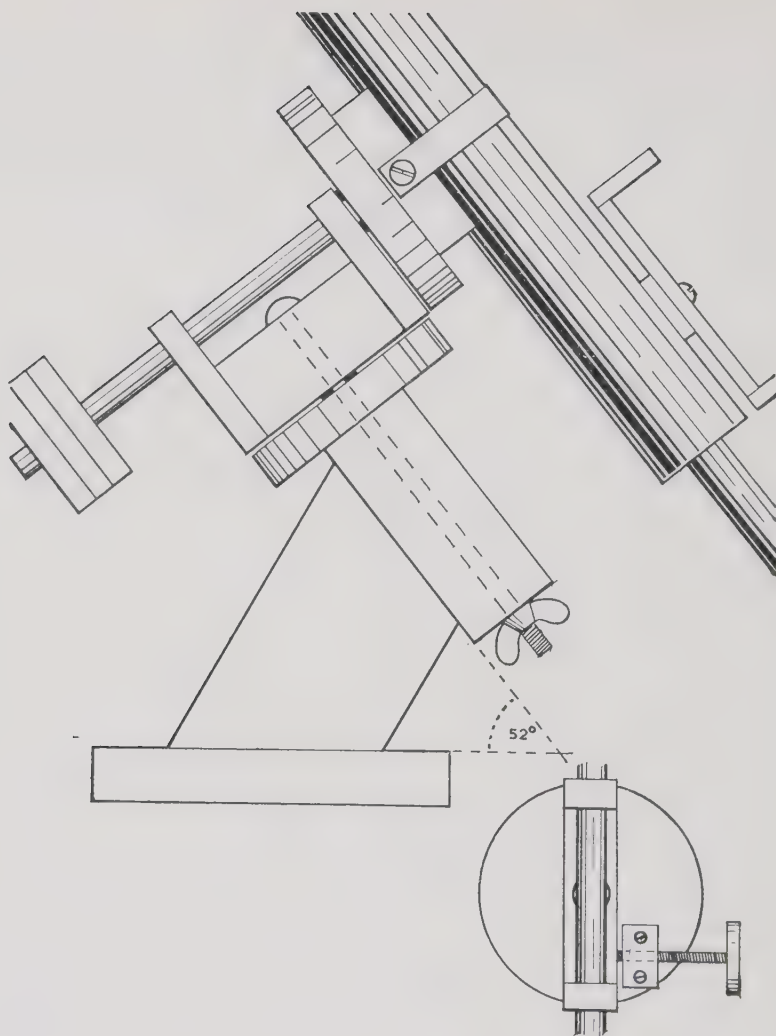


Fig. 69. The mounting of the telescope

The first glance through our telescope will probably be quite a disappointment, as everything seems blurred, but it is only necessary to adjust the position of the ocular by pushing it in a little farther, or by pulling it out a little, and everything will be surprisingly sharp.

A simple test shows us if the telescope has been constructed accurately. We select a star of about 2nd or 3rd magnitude, and direct our telescope at it. The star itself should present a point of light of no appreciable diameter, and it should be surrounded by two or three faint rings of light. If these cannot be seen, and the star appears to throw rays towards one side, our object glass is not at right angles to the axis of the telescope, and we have to adjust this until the star shows the faint rings.

These rings, by the way, are responsible for the resolving limit of the telescope, as they blot out the second of a double star if it is too near the main star. The size of the rings depends on the aperture of the object glass, being the smaller, the larger the diameter of this is, and for this reason close double stars need object glasses of large diameters if we want to see them as doubles.

The winged nut on the hour axis should never be tightened when the telescope is in use. The tube of the telescope should be pushed forward or back a little until it is perfectly balanced, and remains at whatever declination the telescope has been set.

The weights on the other end of the declination axis should counter-balance the telescope with respect to the hour axis, and thus make it possible to set it at any hour angle without having to tighten the nut in order to keep it steady.

The first improvement would be the fitting of a better quality object glass, which can be purchased from an optical firm. These object glasses consist of several lenses, and make a stop in front of them unnecessary, as even without this the images will be perfectly sharp. This then enables us to make use of the full aperture of 2 inches.

Next, the tubes carrying the ocular lenses can be replaced by brass tubes, perhaps even fitted with a rack-and-pinion mounting, and all the lens-holders can be replaced by aluminium fittings turned on a lathe.

A good deal of work goes into the making of such a telescope, simple though it may be, but the labour is well rewarded, and the pleasure derived from it will soon make us forget the tiresome hours spent on its making.

15

Observing with a Telescope

OBSERVING THE stars does not mean casting occasional glances through the telescope at one star or the other, saying: 'Yes, very pretty', and packing the telescope away again. In this manner no satisfaction can be derived, and such aimless occupation soon palls.

However, it is not necessary to go to the other extreme and take up serious research in order to enjoy astronomy, but every observer should plan his activities and keep a record of all he sees.

The observer's notebook is a piece of equipment which is just as important as the telescope itself. Both Uranus and Neptune would have been discovered in the eighteenth century, had the astronomers concerned kept accurate and tidy records of their observations and not relied on their memories. Not until nearly a hundred years later did it come to light that both these planets had been observed long before the dates of their official 'discoveries'.

Astronomical discoveries are, almost always, made on paper, and not behind the telescope. For this reason we should always make a sketch of whatever we see in the telescope, the relative positions of the stars, their brightness, or details of the Moon's or the planets' surfaces. Only by comparing one day's records with those of an earlier date is it possible to say for sure that certain changes have taken place, or that one star apparently moves and turns out to be a comet, or that a 'new star', a *Nova*, has appeared in some area of the sky. It is usually an amateur who makes such discoveries, as the professional astronomer normally concentrates on one particular problem only and may not even be able to tell whether Venus is a morning or an evening star on the day someone happens to ask him that question.

The entries in our notebook must be made while we are actually at the telescope, and for this reason it is necessary to have a little table

standing at the side, with our book and pencil handy. Strong light must be avoided, as it takes several minutes before the eyes regain their full sensitivity after looking at a brightly illuminated sheet of paper, and it has been found that red light is the best for this purpose, as it affects the eyes least. A bicycle rearlight is ideal for this, but we must insert a weak bulb into it, which must give just about sufficient light to make it possible to discern our writing.

Every entry in the notebook is headed with the date and time of the observation, the kind of instrument used (aperture and magnification), the R.A. or the H.A. and the decl. of the part of the sky which we are observing, and, perhaps, the chief object of our observations. Underneath we make a sketch of everything we can see in our field of view, putting the stars at their proper distances from each other, and indicating their approximate magnitudes. Then may follow remarks as to the state of the atmosphere and the weather and whatever else we may want to add.

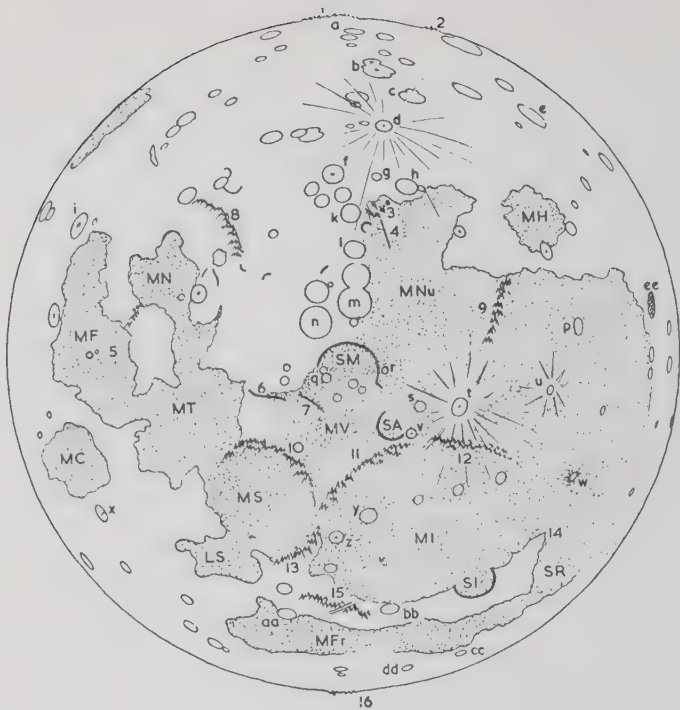
When we are making these sketches, we must always remember that field-glasses present everything *right side up*, while an astronomical telescope shows everything *upside-down*. This, however, has to be taken into account only when we want to compare sketches of the same part of the sky made with the aid of different instruments, or compare them with other star maps.

THE SUN

It is quite impossible to look at the Sun through a telescope without having dark glasses either in front of the object glass, or, preferably, behind the ocular. But a much safer—safer for the eyes—way is to project an image of the Sun on a sheet of white paper, held at a distance of 6 to 12 inches behind the telescope. By adjusting the ocular tube it is possible to obtain a perfectly sharp image, and to see this properly it is best to fit a little screen around the telescope to prevent any direct sunlight from falling on the paper.

Sunspots and other features can be drawn on the sheet on which the image is projected, and in this manner a sketch of the Sun's surface can be made in a very short time.

With a little telescope like our home-made one, there is little else besides the sunspots that is of interest to the observer, but the movement of the spots across the Sun's disk, owing to his rotation, and the development of the spots provides much that is worth studying.



Map of the Moon

CRATERS: *a.* Newton; *b.* Clavius (interior detail); *c.* Longomontanus; *d.* Tycho (with rays); *e.* Schickard (detail); *f.* Walter; *g.* Hell; *h.* Pitatius; *i.* Petavius; *k.* Purbach; *l.* Arzachel; *m.* Ptolemaeus; *n.* Hipparchus; *o.* Messier; *p.* Flamsteed; *q.* Triesnecker (clefts); *r.* Schröter; *s.* Stadius; *t.* Copernicus (rays); *u.* Kepler (rays); *v.* Eratosthenes; *w.* Aristarchus (brightest spot on Moon's surface); *x.* Cleomedes; *y.* Archimedes; *z.* Aristillus; *aa.* Aristoteles; *bb.* Plato (floors seems to vary); *cc.* Anaximander; *dd.* Philolaus; *ee.* Grimaldi (darkest spot on Moon's surface).

OTHER FEATURES: 1. Leibnitz Mts.; 2. Dörfel Mts.; 3. Stag's Horn Mts.; 4. Straight Wall; 5. Rays; 6. Ariadacus Cleft; 7. Hyginus Cleft; 8. Altai Mts.; 9. Riphaen Mts.; 10. Haemus Mts.; 11. Apennines; 12. Carpathians; 13. Caucasus; 14. Cape Heraclides; 15. Alps (with Rift Valley); 16. Mts. of Eternal Light.

LUNAR SEAS: *ls.* *Lacus Somniorum*, Lake of the Sleepers; *mc.* *Mare Crisium*, Sea of Crises; *mf.* *Mare Foecunditatis*, Sea of Fertility; *mfr.* *Mare Frigoris*, Sea of Cold; *mi.* *Mare Imbrium*, Sea of Showers; *mn.* *Mare Nectaris*, Sea of Nectar; *mnu.* *Mare Nubium*, Sea of Clouds; *ms.* *Mare Serenitatis*, Sea of Serenity; *mt.* *Mare Tranquillitatis*, Sea of Tranquillity; *mv.* *Mare Vaporum*, Sea of Vapours; *sa.* *Sinus Aestuum*, Bay of Billows; *si.* *Sinus Iridium*, Rainbow Bay; *sm.* *Sinus Medii*, Central Bay; *sr.* *Sinus Roris*, Bay of Dew.



PLATE XIII. South-western part of the Mare Nubium with the craters Ptolemaeus (*bottom centre*), Alphonsus, and Arzachel (*directly above*), and the curious 'Straight Wall' ending in the Stag's Horn Mountains.

By courtesy of Mt. Wilson Observatory



PLATE NIV. M₃₁ (NGC 224), the Great Nebula in Andromeda. All the individual stars shown on the photograph belong to our own Galaxy and are much nearer than the great Spiral Nebula, the distance of which is one and a half million light years.

By courtesy of Mt. Palomar Observatory



PLATE XV. M₄₂ (NGC 1976), the Great Nebula in Orion. A huge mass of luminous gas, partly obliterated by dark nebulae.

By courtesy of Mt. Palomar Observatory

THE MOON

The most fascinating object for observation with small telescopes is the Moon. Magnifications as low as 10 times show a surprising amount of detail, and most of the larger formations of the surface can be seen with binoculars. The mountains on the Moon are visible only while they are casting shadows, and this is the case only when the *terminator* is near them, which is that line on the Moon which divides the illuminated part of the Moon's disk from the dark part. All along this line the Sun is either rising or setting, and all features of the surface cast long shadows. As the terminator moves across the face of the Moon once every fortnight, all the features can be observed within that period, and the objects best situated for observation are different every day.

The boldest features are the 'seas', which are actually large plains, and contain no water. These are visible even to the naked eye.

Most impressive, when seen through a telescope, are the craters of the Moon, which cover the greater part of her surface, and especially near the Moon's South Pole there are literally thousands of them. Most of the craters are named after famous men of science, especially astronomers, and many of these craters are higher than any of the mountains on Earth.

Then there are the mountain ranges, usually named after the large mountains on Earth, and smaller features include clefts, walls, and rays, some of which are marked on our map of the Moon.

This map provides us with the outlines of the lunar features, and our own observations must supply the finer details. Here again our sketches should be compared with those of an earlier date, as there have been many instances where changes have been observed on the Moon's surface.

Unfortunately we can never see more than half of the Moon's surface. The period of rotation around her axis is exactly the same as the period of revolution around the Earth, and so the Moon always presents the same side to us. There is, however, nothing which indicates that the other side of the Moon may be different from the side which we can see, but for the proof of this we shall have to wait until the first space-ship completes a trip around the Moon.

THE FEATURES OF THE MOON

Two days after New Moon: When the Moon becomes first visible in the evening sky after New Moon, the crater Petavius presents a striking

picture. Its walls and the centre mountain cast remarkable shadows, and it may just be possible to glimpse a cleft which runs from the central peak to the outer wall.

In the middle of the crescent is Longremus, and farther down (as seen through the inverting telescope), is the Mare Crisium, which is surrounded by high mountains. This Mare is not perfectly level, but contains many ridges and winding banks.

There are numerous craters in the South, and at the southern cusp of the crescent are the Leibnitz Mountains, which are the highest mountains on the Moon. In the North, exactly at the pole, we find the Mountains of Eternal Light, so called because the Sun never sets on their summits.

Moon about 4 days old: Petavius is now almost invisible, and the Mare Crisium appears as a featureless oval spot. But on the edge of it there is now a yellowish area, which is called Palus Somnii (Marsh of Sleep), which opens into the Mare Tranquilitatis. Farther north is the Mare Serenitatis with the Caucasus and Haemus Mountains.

South of the Mare Tranquilitatis we find the Mare Nectaris, on the eastern side of which lies the crater Theophilus which has a central mountain. To the South of this are the Altai Mountains, but these are best seen about 4 days after Full Moon, when the shadows fall in the opposite direction, over the plains.

Moon at First Quarter: In the centre we find the two giant craters Hipparchus and Ptolemaeus, from which a string of smaller craters stretches right to the South Pole. North of these two craters is the Sinus Medii (Central Bay), so called because of its position in the centre of the Moon's disk.

At the western side of the Sinus Medii we find the small crater Triesnecker, and just north of it is a very small one, Hyginus, which is cut into two by a cleft which is over 100 miles long. Towards the west of this one we find another cleft, the Ariadaeus Cleft. Both of these are visible in quite small telescopes, and they even show up very well on photographs, as is illustrated by Plate XII.

Two days after First Quarter: The Mare Nubium comes into view now, and in the North are the Apennines which separate the Mare Vaporum from the Mare Imbrium. The latter is bounded in the North by the Alps, a striking feature of which is the great valley, thought to have been caused by a large meteor grazing the Moon's surface and cutting right through the mountains.

Moon about 10 days old: The Alps are still clearly visible, and at their eastern side Plato comes into the sunlight now. The floor of this

crater seems to alter as the lunar day wears on, becoming darker as if it becomes covered with some kind of vegetation.

On the opposite side of the Mare Imbrium are the Carpathian Mountains, and beyond lies Copernicus, a large crater with much interesting detail and surrounded by a system of bright rays.

In the south-west corner of the Mare Nubium we find a curious feature, which is known as the Straight Wall. This is a cliff, nearly 70 miles long and in places several thousand feet high. This is perfectly straight, and it ends in a group of hills known as the Stag's Horn Mountains. (*See Plate XIII.*)

Farther south we find Tycho, another crater which is surrounded by bright rays, and these make it the most prominent feature at Full Moon. Still farther to the south is Clavius, a crater which has a diameter of nearly 150 miles, and its inside lies considerably below the level of the surrounding country, so that the height of the walls, measured from the inside of the crater, is over 3 miles. Its walls are broken in many places by cracks, and by two smaller craters, and there are several small craters right inside Clavius.

At Full Moon: Near the north-east limb we find Aristarchus, the brightest spot on the Moon's surface, and the darkest spot, Grimaldi, is near the eastern limb. Also on the limb, a little towards the east from the South Pole, and in front of the Dörfel Mountains, lies Bailly, the largest crater on the Moon. It is over 180 miles in diameter, and its walls are full of ridges and smaller craters.

The only other features visible at Full Moon are the dark portions of the Moon's surface, and the bright rays surrounding the craters Aristarchus, Copernicus and Tycho.

After Full Moon: All the features of the Moon's surface become visible again in the same order while the Moon is waning, but the shadows are on the opposite sides of all the mountains. It is well worth-while to study the different features under different illuminations, as usually new detail becomes visible, which was not apparent at first.

THE PLANETS

Mercury is so close to the Sun that it can be observed only for a short while before sunrise or after sunset at the times of its elongations. But even then it depends on the position of the ecliptic whether or not it is sufficiently high in the sky to make observation possible. At its

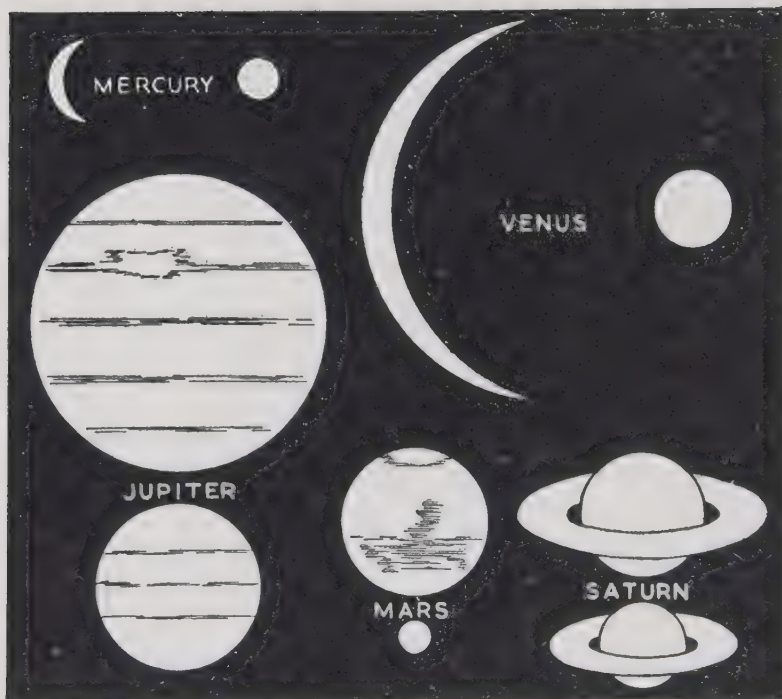


Fig. 70. Sizes of the planets as seen from the Earth

brightest, Mercury can reach mag. -1.8 , but it is never very conspicuous, owing to the brightness of the sky at the time of its visibility.

Venus is the brightest of all planets, being of mag. -4.5 at maximum, and it can often be observed in bright daylight. Both Mercury and Venus show phases, like the Moon, and these are clearly visible in small telescopes, but neither of them exhibits any surface detail. Their sizes, near upper and lower conjunction, differ greatly, as is shown in Fig. 70.

Mars can be seen as a little reddish disk, without any detail, and it is of little interest. At opposition, its magnitude may reach -2.5 , but it is usually much less than this.

Jupiter is a very fine object for small telescopes, and even for binoculars. The boldest surface features can just be seen in a 1-inch telescope, and the four largest of its satellites present a different aspect every day.

Quite frequently it is possible to observe a 'lunar eclipse' when one of these little 'moons' is blotted out by the shadow of the planet. Jupiter's magnitude at opposition is about -2.5 .

Saturn with its rings is also an interesting object for small instruments, but no detail is visible on its disk. The largest of its satellites, Titan, may be visible under favourable conditions, but most of the time it is too close to the planet to become visible in a 1-inch telescope.

The magnitude of Saturn varies greatly, depending on the inclination of the rings by which the planet is surrounded. Our little telescope shows these very clearly, but they are not always visible. Every 15 years we look at them edgewise, and as they are not thick enough, they remain invisible in even the largest of instruments.

The other planets, Uranus, Neptune and Pluto, as well as the minor planets, several thousand of which circle the Sun between the orbits of Mars and Jupiter, are of little interest to the observer who uses only small instruments. Uranus and Neptune can only just be seen in a 1-inch telescope (they are invisible to the naked eye), but it is not possible to distinguish them from stars, except by constant observation, which would reveal their orbit. Pluto, however, is invisible in all but the very largest telescopes.

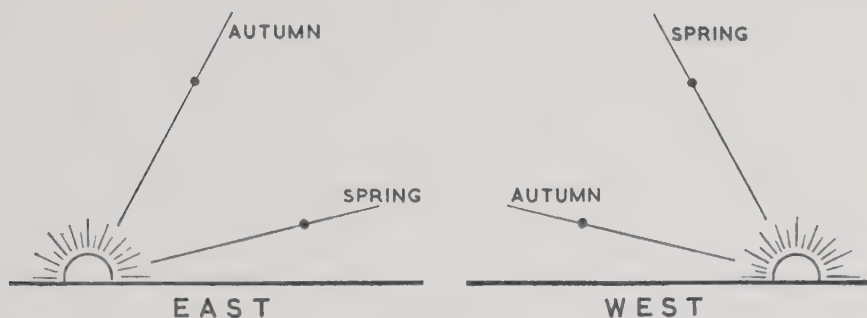


Fig. 71. At western elongation, Mercury is best seen in the autumn in the mornings, when the ecliptic makes a large angle with the horizon. At eastern elongation it is best to observe him in the spring, just after sunset in the west

VARIABLE STARS

Stars which vary in brightness have been the greatest riddle of astronomy for a very long time, but now well over 10,000 such stars

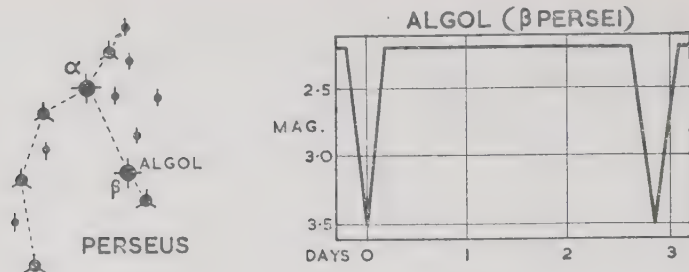
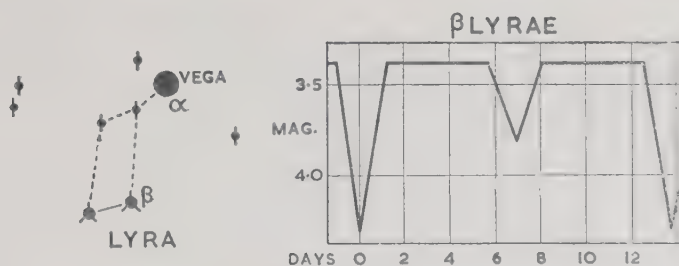


Fig. 72. Dark eclipsing variables (Algol-stars)

DARK ECLIPSING VARIABLES	R.A.	DECL.	MAGNITUDE		PERIOD
			MAX.	MIN.	
β Persei	3.05	40.8°	2.2	3.5	2.867 days
R Canis Majoris	7.17	-16.3°	5.4	6.1	1.136 „
δ Librae	14.58	- 8.2°	4.8	6.2	2.327 „
λ Tauri	3.58	12.3°	3.3	4.2	3.9 „

have been studied, and it was found that there are different types, each with its own peculiarities. Their observation affords a useful and interesting study, especially as the observation of these stars is almost entirely in the hands of amateurs who determine the brightness of such a star at its maximum and at its minimum by comparing it with other stars, and they also determine the periods of these stars, that is the time from one minimum to the next.

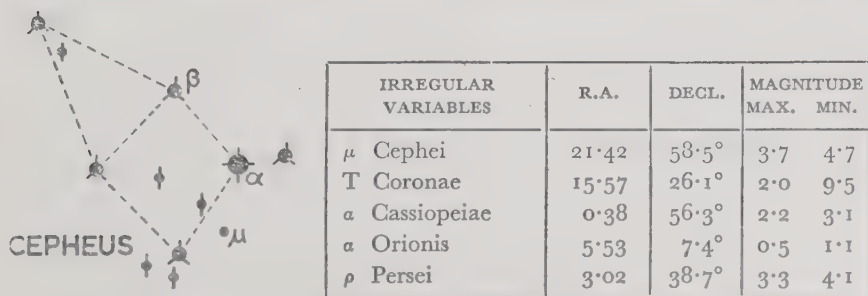
The star Algol is the most famous of the variable stars. It belongs to the group of the *dark eclipsing variables*. These actually consist of two stars, one fairly bright, and the other almost dark. The two stars revolve around one another, and if the plane of their orbits happens to be in our line of sight, the dark one eclipses the brighter one during each revolution. Because of their nature, their period is perfectly constant; in the case of Algol it is 2 days, 20 hours and 49 minutes. The normal magnitude of this star is 2.2 and once during each period this sinks to 3.5 within 5 hours. Its brightness begins to increase immediately after the minimum, and after another 5 hours the star shines with its usual magnitude.

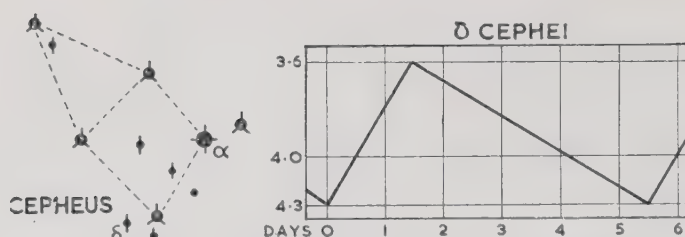
Fig. 73. Bright eclipsing variables (β Lyrae-stars)

BRIGHT ECLIPSING VARIABLES	R.A.	DECL.	MAGNITUDE		PERIOD
			MAX.	MIN.	
β Lyrae	18.48	33.3°	3.4	4.3	12.9 days
68 Herculis	17.15	33.5°	4.8	5.4	2.05 „
U Ophiuchii	17.14	16.3°	5.7	6.4	1.68 „

Bright eclipsing variables also consist of two stars, but with these both stars are luminous bodies, and the relation between their period and their apparent magnitude is shown in Fig. 73. In each period there are two minima, and their 'depths' depend on the relative brightness of the two bodies concerned. The periods of variables of this kind are also perfectly constant, and the best-known star of this type is β Lyrae.

Herschel's Garnet Star is the prototype of the *irregular variables*, and they have no fixed period, nor are the magnitude ranges between maximum and minimum constant. These stars offer tremendous scope for the amateur observer, and a few of them are named in Fig. 74.

Fig. 74. Irregular variables (μ Cephei-stars)

Fig. 75. Short period variables (δ Cepheids)

CEPHEID VARIABLES	R.A.	DECL.	MAGNITUDE		PERIOD
			MAX.	MIN.	
δ Cephei	22.27	58.2°	3.6	4.3	5.4 days
ζ Geminorum	7.01	28.6°	3.7	4.3	10.2 „
η Aquilae	19.50	0.9°	3.7	4.5	7.2 „

With these stars it is a change in their physical constitution which brings about the change of brightness, but the real cause of their variability has not yet been explained satisfactorily.

Cepheids are also pulsating stars, like the irregular variables, but they are most regular in their habits, and it is almost as though these stars were 'breathing'. Their periods range from a few hours to a month or two, and the star δ Cephei gave the group its name. The rise in brightness from minimum to maximum occupies an appreciably shorter time than does the fall from maximum to minimum afterwards. Their real brightness at maximum is directly proportional to their period, and it is thus possible to calculate their distances from us by comparing their apparent magnitudes as we see them, with the real magnitudes of these stars as established by their period.

The last type of variable stars are the *long-period variables*. Their periods range from about 2 months up to two years, but usually there are some irregularities and maxima and minima may occur sooner or later than indicated by the average period. $\omicron$ Ceti was the first of these stars which has been discovered, and on account of its behaviour it was called *Mira*, the Wonderful One.

The average period of *Mira* is 11 months, and the brightness varies between mag. 1.7 and 10. Sometimes, however, the maxima are of mag. 4.5 only, and the minima of mag. 9. *Mira*, therefore, is quite a conspicuous object at times, and is visible for about 6 months. After

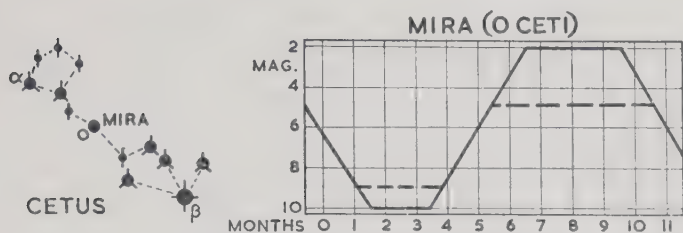


Fig. 76. Long-period variables (Mira-stars)

LONG-PERIOD VARIABLES	R.A.	DECL.	MAGNITUDE		PERIOD
			MAX.	MIN.	
α Ceti	2 ^h 17	-3 ^h 2 ^m	1.7	9.5	330 days
R Cassiopeiae	23 ^h 55	51 ^h 1 ^m	5.3	12.0	434 "
η Geminorum	6 ^h 12	22 ^h 5 ^m	3.2	4.2	231 "
χ Cygni	19 ^h 49	32 ^h 8 ^m	4.2	13.7	409 "

that, it is invisible to the naked eye for 5 months, and it takes at least a 2-inch telescope to see it at minimum. Fig. 76 shows Mira's light-curve, and its position in the constellation Cetus. These stars also present problems which have not been solved yet, and the amateur can give a good deal of help by observing the brightnesses of these stars and observing their periods.

DOUBLE STARS

These are stars which to the naked eye appear as a single point of light, but when viewed through a telescope are found to consist of two separate stars. In many cases these two stars merely happen to be in the same line of sight, one far behind the other, and in this case they are called *optical double stars*. Binaries, however, are double stars whose components revolve round each other, their periods of revolution sometimes being as long as several hundred years. Only repeated observation makes it possible to distinguish between the two, and in order to compare their positions accurately, the distance between the two components, expressed in seconds of arc, is not sufficient; the *position angle* must also be stated. This is the angle which the line joining the two components makes with the hour circle passing through the

brighter of the two. This angle is measured from 0° to 360° starting from the north point of the hour circle, and continuing anti-clockwise.

This hour circle can be made 'visible' by attaching a single thread of a spider's web across the stop in the ocular of our telescope, and once this has been turned into the proper position, it will always indicate the position of the hour circle, whatever the position of the telescope. North, of course, is always at the bottom.

Double stars are severe test-objects for telescopes, and the light-gathering power of the object glass, depending on its aperture, determines the faintest star shown, but only a really good object lens will actually show a star of such magnitude in the vicinity of a brighter one. The aperture also determines the closest double star which the telescope will resolve into its components, and under good conditions a good object lens should show and separate doubles as indicated by the following table:

APERTURE	CLOSEST DOUBLE STAR SEPARATED	FAINTEST STAR SHOWN
1 in.	4.6"	mag. 9
1½ in.	3.0"	" 10
2 in.	2.3"	" 10.5
2½ in.	1.8"	" 11
3 in.	1.5"	" 11.5

CLUSTERS AND NEBULAE

Clusters and nebulae have been catalogued first by the astronomer Messier, who made a list of 103 of these hazy patches in the sky. He assigned a number to each object, and the Great Nebula in Andromeda is thus designated M 31.

Herschel's more comprehensive catalogue was enlarged by Dreyer in 1888, and is now known as the New General Catalogue. Again, each object has a number, and M 31 in this catalogue appears as N.G.C. 224.

There are two different types of star clusters, both of which belong to the system of our Milky Way. The first are the open clusters, of which about 350 are known, and the second type are the globular clusters, over 100 of which have been found so far.

The open clusters are condensations of stars within the Milky Way System, and the Sun belongs to one such cluster, as do many of the

brighter stars which we can see on any clear night. Typical of this class are the Pleiades, the Hyades, the Praesepe, and the Double Cluster in Perseus. (*See Plate XVI.*)

Globular clusters surround the Milky Way on all sides, and for this reason they are much farther away. They contain many thousands of stars, some of them even millions. The best known of these is M 13, in the constellation Hercules, which is shown on Plate XVII. These clusters contain a great number of Cepheid variables and their distances are therefore accurately known.

NEBULAE

There are several types of nebulae which belong to our Milky Way, and also some which are outside our stellar system. The Great Nebula in Orion (Plate XV) is representative of the gaseous nebulae, huge masses of incandescent gas, often of a distinct greenish or bluish colour. They have no distinct shape, and are often associated with stars.

Dark nebulae are masses of cosmic dust, which blot out the light of stars which are behind them, and they are often called 'coal sacks', because of their appearance among their surroundings of the faint stars of the Milky Way. Dark nebulae are found in the constellations Orion, Auriga, Cygnus, Aquila, and Taurus.

Planetary nebulae are masses of non-luminous matter or gases which are illuminated by a star which is usually situated at the centre of the nebula. The Ring-Nebula in the constellation Lyra is one example, and this one is easily visible in a small telescope. The central star, however, needs a 12-inch telescope to render it visible as it is of magnitude 15 only.

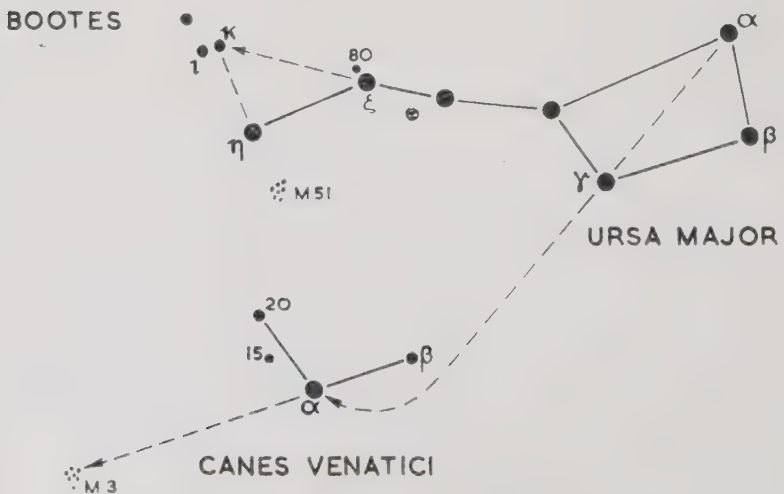
The extra-galactic Nebulae are either of the irregular type, accumulations of stars outside our galaxy, with no distinct shape, like the two Magellanic Clouds, seen from southern latitudes, and having the appearance of detached portions of the Milky Way, or else they are spiral nebulae, stellar systems like our own Milky Way. The nearest of these is the Great Nebula in Andromeda, shown on Plate XIV. Their distances are reckoned in millions of light-years, and only few of them are visible in small telescopes, but millions of faint ones have been photographed; in fact, photographs which show the very faintest objects reveal that at these magnitudes there are many more spiral nebulae than there are stars.

16

140 Interesting Objects in the Sky

BEFORE WE start our observations we must consider the conditions under which we have to work. The bright nights of the summer are useless for the observation of faint stars and nebulae, and so are those nights on which the Moon shines brightly.

In the winter, the scintillating of the stars indicates that the atmosphere is not very steady, and it will not be possible to separate close double stars. The best conditions are usually found in autumn and spring, when the sky is clear, and no haze is in the air. The light of the



Map 9. Great Bear, Hunting Dogs and Herdsman

stars is then steady, and the background of the sky has a 'velvety' appearance. But experience is worth more than book-knowledge, and the observer will soon know himself whether or not it is worth getting out his telescope, once he has glanced at the sky.

The star Mizar (ζ Ursae Majoris) is curious for two reasons. At a distance of $11' 47''$ there is the little mag. 5 star Alcor (80 Ursae Majoris), which can be seen quite easily on any clear night. If not, the slightest optical aid will reveal it. The star ζ itself is a double star, the first which was ever discovered. The brighter of the two is of mag. 2.4, and at the distance of $14''$ there is another star of mag. 4.2. Throughout these notes we shall write in an abbreviated manner: Double, mags. 2.4; 4.2 $D = 14''$.

From ζ we can easily find a little triangle of stars which belongs to the constellation Bootes. Here, ι is an easy double, mags. 5; 7.5 $D = 38''$. The leader, κ , is also a double, but a little more difficult. Mags. 4.7; 7.2 $D = 13''$, the companion star, in this double, is bluish.

On the other side of η , but not quite as far away as the little triangle, we find M 51, in Canes Venatici, a spiral nebula which is 3 million light-years away. It is another galaxy, and its brightness is equal to a mag. 8.5 star. It can therefore be seen in a telescope only.

A line from α over γ Ursae Majoris brings us almost to the star α Canum Venaticorum, which also has the name Cor Caroli, the Heart of Charles II. This is an easy double star, mags. 2.9; 5.4 $D = 20''$. The colour of the primary is white, and that of the companion bluish. 15 is not always visible to the naked eye, because of its faintness, and this, too, is double, mags. 5.5; 6 $D = 290''$.

The line from β over α in the Hunting Dogs brings us to the position of M 3, a globular cluster, whose distance from us is 40,000 L.Y. and its magnitude about 4.5; it is, therefore, quite conspicuous and can just be seen without instrumental aid on a clear night.

The Pole Star itself is a double, mags. 2.1; 8.8 $D = 19''$. The great difference in brightness of the two components, however, makes it extremely difficult to separate the two, and a small instrument as our home-made one will be able to separate them only on exceptionally clear nights.

The line of the Tail-Stars of the Little Bear points roughly at Σ 634 in Camelopardus, and although there are a few other stars nearby, it can easily be recognized because it is just a little brighter than all the other ones. It is a double star, mags. 4.5; 8 $D = 9''$.

From β over η in Ursa Minor, we come to a little triangle of stars which is part of Draco. Here, ψ is an easy double, mags. 4; 5.2 $D = 30''$.

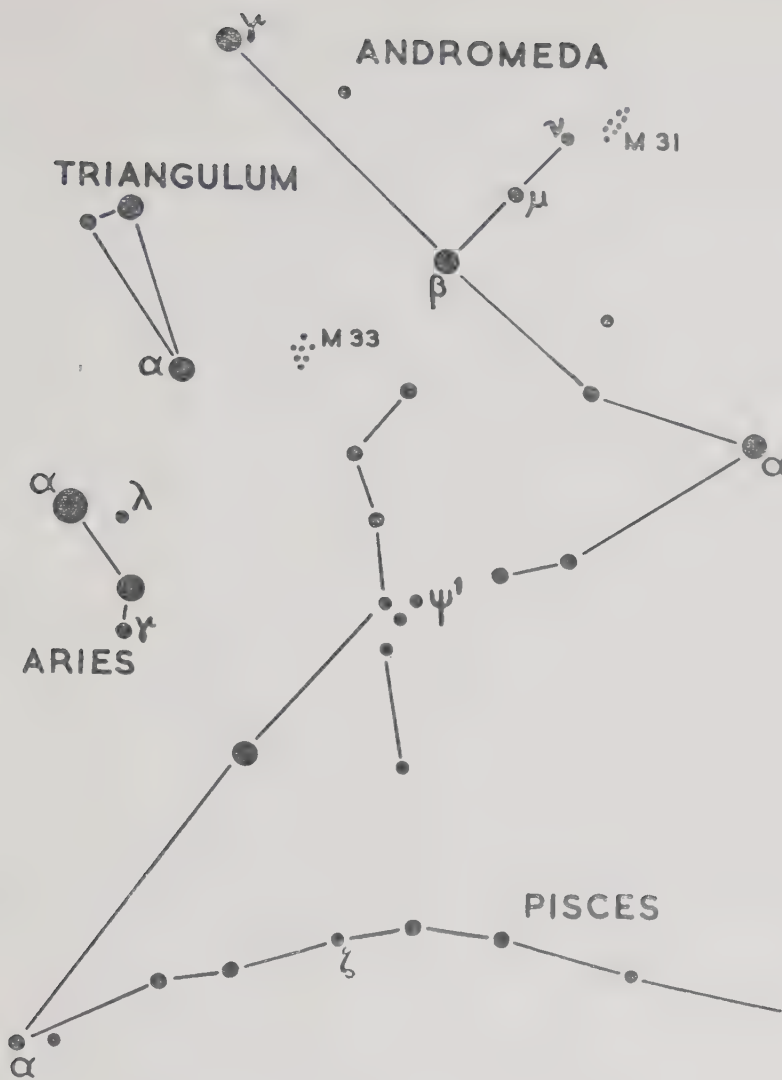


Map 10. The Little Bear, Giraffe, Dragon and Cepheus

Half-way between this triangle and γ Cephei, we find κ , which belongs to Cepheus. This is a rather more difficult double, mags. 4; 8 $D = 7''$.

The star δ Cephei is a very easy double star, mags. 3.6; 7.5 $D = 41''$. The colour contrast between the two is really striking, the primary being yellow and the companion blue. The primary of δ Cephei is a variable star, being the prototype of the Cepheids. The range of magnitude is 3.6—4.3, and the period $P = 5.37$ days.

ξ Cephei is rather a difficult double, although the components are relatively bright, mags. 4.7; 6.5 $D = 7''$. It is situated right in the middle of the Cepheus quadrangle.



Map 11. Andromeda, Triangle, Ram and Fishes

μ Cephei, just below the base lines and half-way between α and ζ , is known as Herschel's Garnet Star, on account of its deep red colour. It is an irregular variable, the range of magnitude being between 3.7 and 4.7.

In the Head of the Dragon, we find ν , a wide double star, which is a very fine object for observation. Its two components are of exactly the same brightness, mags. 4.6, and their distance is 62".

The easternmost star of Andromeda, γ , is a magnificent object in small telescopes. Two stars, one of them of a golden colour and the other blue-green, are separated by 10". Their magnitudes are 3 and 5 respectively. The stars μ and ν lead us almost to M 31, the Great Nebula in Andromeda. This is visible to the naked eye and is very well seen in small telescopes as a long oval, rather brighter in the centre. M 31 is an island universe like our own galaxy; its distance from us is about $1\frac{1}{2}$ million L.Y.

Another spiral nebula, M 33 in Triangulum, is found on the other side of β Andromedae. This, again, is a galaxy, almost at the same distance from us as M 31. It appears very large, but ill-defined, and is not very well seen in small instruments of high magnification.

Below the Triangle we find the Ram, and here γ is an easy double, mags. 4.2; 4.4 $D = 8''$. The two stars are easily separated even by small instruments, and λ is also an easy double, mags. 5; 7.5 $D = 39''$.

In the straggling line of stars which belongs to the constellation Pisces, ζ , the fourth star in front of α is an easy double, mags. 5.5; 6.5 $D = 24''$, and from α in Andromeda a line of stars leads us to a little triangle in the Fishes, where the uppermost, ψ^1 , is also double, mags. 5.5; 6 $D = 30''$.

α Cassiopeiae is an irregular variable, its magnitude ranges from



Map 12. Cassiopeia and Perseus



PLATE XVI. NGC 869 and NGC 884. The Double Cluster in the Constellation Perseus, which is just visible to the naked eye.

By courtesy of Mr. Roberts



PLATE XVII. M 13 (NGC 6250). The Globular Cluster in the constellation Hercules, one of the finest objects of its kind in the sky.

By courtesy of Mt. Palomar Observatory

2.1 to 3.1 and it has an average period of 80 days. α has a 9th mag. companion at 62" distance, and on a clear night the colour contrast is really striking, the primary being reddish, and the Comes is blue.

A number of faint stars indicates the way to R Cassiopeiae, a long-period variable of deep red colour. At maximum it is of mag. 5, and at minimum mag. 12. Its period is 430 days.

γ is an irregular variable, mag. 1.6—3, and it has a 9th mag. Comes at 430" distance. Between α and γ we find η , which is double, mags. 3.5; 7.7 $D = 10''$.

The stars γ and δ point at the double cluster in Perseus, consisting of N.G.C. 869 and N.G.C. 884. Each of these contains about 700 stars, and their distance from us is about 4,400 L.Y. Even in small telescopes these present a beautiful sight, and they are visible to the naked eye on clear, moonless nights.

η , the first star of Perseus following the double cluster, is double, mags. 4; 8.5 $D = 28''$, and α is worth seeing on account of its beautiful surroundings. It is situated in a shining field of faint stars. ϵ is also a double, but closer than η , mags. 3; 8 $D = 9''$.

Algol is the prototype of the dark eclipsing variables. For about 59 hours, Algol is of mag. 2.3, and then its light diminishes, until, 5 hours later, mag. 3.5 is reached. Almost immediately, the increase in brightness starts, and after another 5 hours, the 'eclipse' is over.

Just below Algol we find ρ , a variable of the μ Cephei type (irregular) mag. 3—4, approximate period 910 days.

Just below Capella is a little triangle of stars in which ϵ is very remarkable. It is a bright eclipsing variable, but there is no perceptible secondary minimum, because one of the stars is a Super-Giant, and the other a Dwarf.

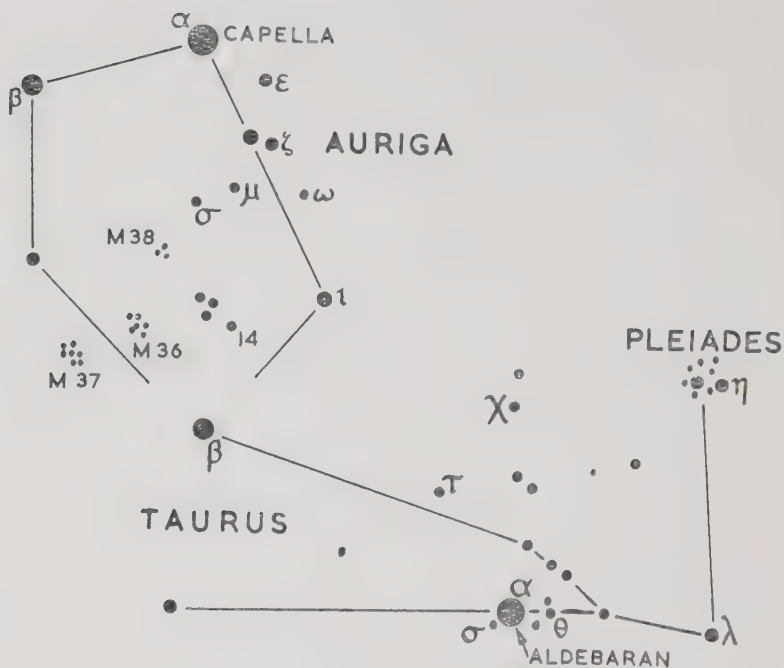
We only notice the eclipse of the Dwarf, but the light of the larger star is not appreciably diminished when the little one is in front of it. This variable has the remarkably long period of over 27 years, and its magnitude ranges from 3 to 4.

ζ is also an eclipsing variable, mag. 5—5.5, $P = 972$ days.

Below this triangle we find ω , rather a difficult double, because of the proximity of the components. Mags. 5; 8 $D = 6''$.

There are three very fine open clusters in Auriga, M 38, composed of 120 stars, 2,900 L.Y. away, M 36, 70 stars, distance 3,200 L.Y. and M 37, 270 stars, $D = 2,700$ L.Y. Small telescopes do not show all the stars of these clusters, but all three are well worth searching for.

On the line from α to β , we find a little triangle of stars, and just below this there is 14 Aurigae, a faint double, mags. 5; 7 $D = 15''$.



Map 13. The Bull and the Charioteer

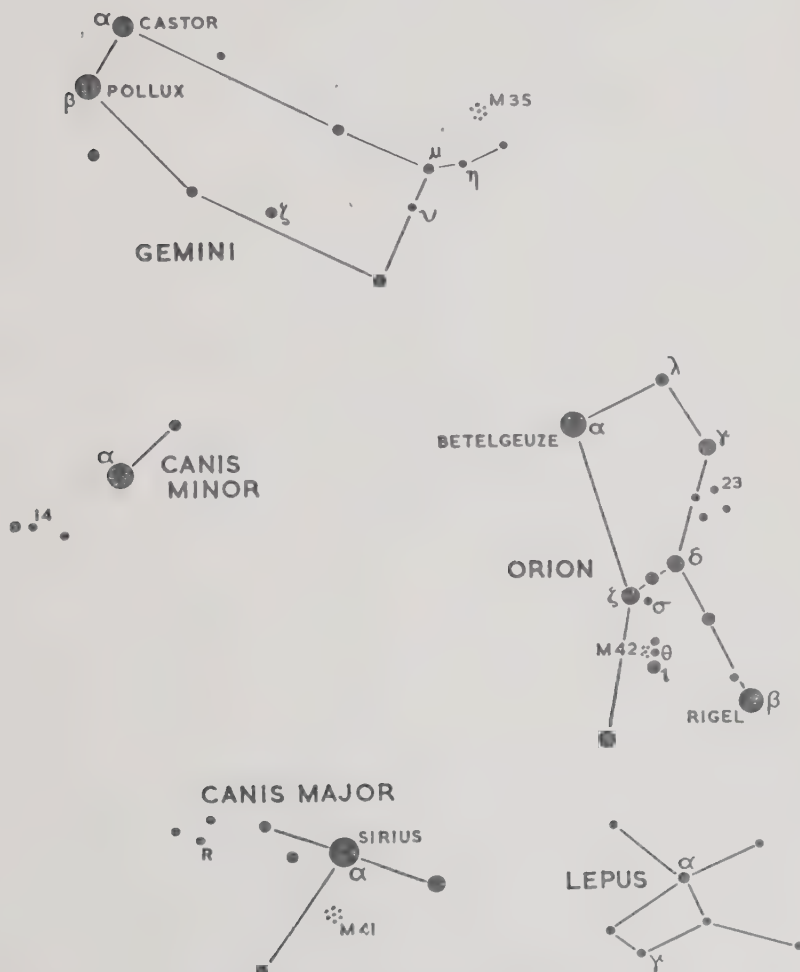
Following Aldebaran in the constellation Taurus is σ , a naked-eye pair; both stars are of mag. 5 and their distance is $4' 30''$. Preceding Aldebaran there is another naked-eye double, θ , mags. 3.5; 4 $D = 335''$. The northerly of the two is yellow, and the southern is green. This contrast is particularly marked when seen through binoculars.

In front of the 'V' of the Hyades, is λ , an eclipsing variable, mag. 3.8–4.1 $P = 3.95$ days, and τ north of and following α is a fairly easy double star, the primary being white and the companion blue, mags. 4.5; 7 $D = 63''$. χ is also double, but rather more difficult, mags. 5.5; 8 $D = 20''$.

M 45, the Pleiades, is a most beautiful object in small instruments. There are several hundred stars in this cluster, which is at a distance of 500 L.Y. from us, and it has a diameter of 20 L.Y. The naked eye can usually distinguish only six or seven stars, but on rare occasions eight or nine may be seen. A small telescope, however, shows several dozen.

The brightest star in the Pleiades is Alcyone, η Tauri, and this is a triple star, mags. 3; 7; 7 $D = 117''$ and $120''$.

The two brightest stars of Orion both have their peculiarities. Betelgeuze, α Orionis, is an irregular variable, changing in brightness from mag. 0.1 to 1.2 during an average period of 6 years, and Rigel, β Orionis, is a double star, the two components showing a beautiful contrast, being yellow and blue, mags. 0.3; $7 D = 9''$. It is, however, an extremely difficult double, and our home-made instrument will not



Map 14. The Hunter, Hare, Great and Little Dog, and Twins

be able to separate the two components because of the immense brightness of the primary. δ , the leader of the three stars in Orion's belt, is rather a difficult double, too, for the same reason, mags. 2; 7 $D = 53''$. Between this star and γ we find a little quadrangle, the uppermost of which, 23, is an easy double star, mags. 5 and 7, $D = 32''$.

Just below the Belt is θ , a triple star, mags. 6; 7; 7; $D = 41''$ and $13''$. θ , the middle star in Orion's Sword, is called the Trapezium, consisting of four stars, but our instrument will probably show only three, mags. 6; 7; 7; 8. θ is situated at the centre of the Great Nebula in Orion, M 42, which is an irregular gas nebula, brought to incandescence by the stars within. Binoculars show it to be of a distinct greenish colour, and on clear nights it is just visible to the naked eye. Photographs have revealed that the extent of this nebula is much greater than the parts seen in even the largest telescopes, and it covers almost the whole of the constellation.

The southernmost star in the Sword is a fairly easy double star, mags. 3; 7 $D = 11''$; the primary is white and the companion blue.

Underneath Orion is the little constellation Lepus. Here, α is a very difficult double, mags. 4; 9.5 $D = 35''$. The brighter of the two is pale yellow and the Comes is dull grey. γ is much easier, mags. 4 and 7, $D = 95''$, colours yellow and reddish.

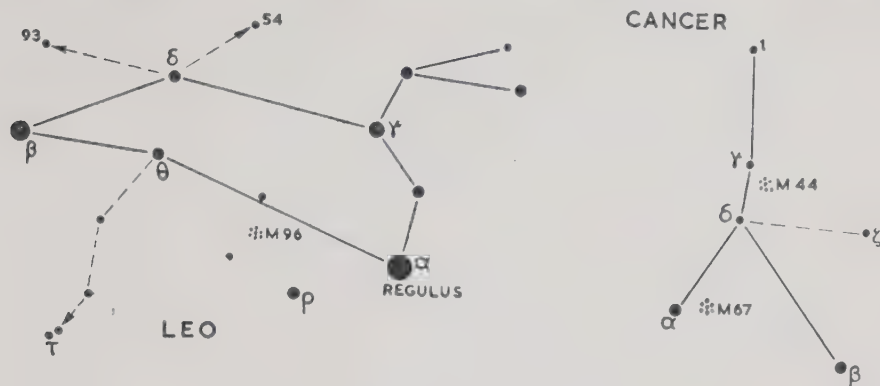
The belt stars of Orion point at Sirius, the brightest star in Canis Major. 4° below this star we find M 41, a beautiful open cluster, consisting of about 150 stars, which is 1,350 L.V. distant. It is easy to see in binoculars, and might just be visible to the naked eye on clear nights.

Following Sirius is a triangle of stars, the lowest of which, R, is a variable of the Algol type. Mag. 5.9—6.7; $P = 1.14$ days.

Following α in the Little Dog are three faint stars, the centre one of which, 14, is a triple star, and is quite easy to see. Mags. 5.5; 7; 8 $D = 76''$ and $112''$.

North of Canis Minor are the Twins, and we have read in an earlier chapter of this book that Castor actually consists of six stars. It may just be possible to separate the two brightest of these with our telescope. Their separation is only $5''$ and the magnitudes of the components are 2 and 3.5.

At the other end of the quadrangle of Gemini is η , a long-period variable, mag. 3.2—4.2; $P = 321$ d, and just above it is M 35, a fine object, consisting of some 500 stars. Our telescope will show quite a few of them, particularly the brighter ones in this cluster.



Map 15. Lion and Crab

ν is another double star, mags. 4; $8 D = 112''$, and so is ζ , mags. 4; $7 D = 94''$. With the latter we should note the contrasting colours, yellow and blue. The primary of this star is a variable of the Cepheid type, mag. $3.7-4.3$, $P = 10$ days.

Regulus (α Leonis) is rather a difficult double, because of the brightness of the primary, and the large separation between the two components cannot make up for this. Mags. $1.8; 8 D = 177''$. β , however, can be separated with opera-glasses already, and, were it not for the faintness of the companion, it could be resolved by the naked eye. Mags. $3; 7 D = 18' 55''$. γ is difficult again, mags. $2.4; 3.5 D = 4''$, and this can be separated only with binoculars or telescopes which have an aperture of over 1 inch.

A line from β over δ brings us to 54, which is also double, mags. $4.5; 7 D = 6''$, and the line from γ over δ points at 93, which is difficult because of the faintness of the companion star, mags. $4.8; 8.4 D = 74''$.

From θ a line of stars brings us to τ , an easy double with striking colour contrast: yellowish and pale blue, mags. $5.4; 7 D = 90''$.

Half-way between θ and α , a little below the line connecting the two, we find M 96, a spiral nebula.

Preceding Leo is the inconspicuous constellation Cancer, and here ϵ is a double with a beautiful colour contrast. A yellow star of mag. 4.2 has a mag. 7 companion which is of bluish colour, $D = 31''$.

M 44, the Praesepe, is an open cluster. On clear nights, the naked eye is able to resolve this into individual stars. The cluster consists of 500 stars, and even binoculars show already 100 of them.



Map 16. The Virgin and Berenice's Hair

Closely preceding α is M 67, another open cluster of about 500 stars, and to the west of δ we find the rather difficult double ζ , mags. 5; 5.5 $D = 5^\circ$.

γ Virginis is a binary star, that is, a double star whose two components revolve around their common centre of gravity, without, however, eclipsing each other. Their period of revolution is about 180 years. The orbits of these stars are so situated that at times they are easily separated by the smallest instrument, and at others even the largest show γ as a single star. At the moment, the two components, both of mag. 3.3, are at a distance of about 5", but they are approaching each other, and in 2016 the distance separating the two will be only a fraction of a second of arc.

The star τ is difficult because of the faintness of the Comes, mags.

4; $9 D = 80''$, and S, lowest of three stars north of Spica, is a long period variable, mag. 5.6—12.3, period 370 days.

The area between σ and ϵ Virginis, stretching towards Coma Berenices, was called by the Arabs the Retreat of the Howling Dogs, and this is well worth sweeping over with a telescope, for it is here that Herschel found hundreds of spiral nebulae, quite a few of which are visible in small instruments.

On a clear night, it is possible to recognize individual stars in the very open cluster below 15 in Berenice's Hair, and in this 17 is an easy double, mags. 5.6; $6 D = 145''$. Lower down we find 24, which is much closer, mags. 5.2; $6 D = 20''$. The two stars show a distinct colour contrast, the brighter being yellow and the fainter blue.

The middle one of three stars preceding α is a naked eye double, but if the night is not perfectly clear, it may not be possible to see it as such. But even opera-glasses are sufficient to separate the two components. They are the stars 32 and 33, mags. 5.5; $6 D = 195''$.

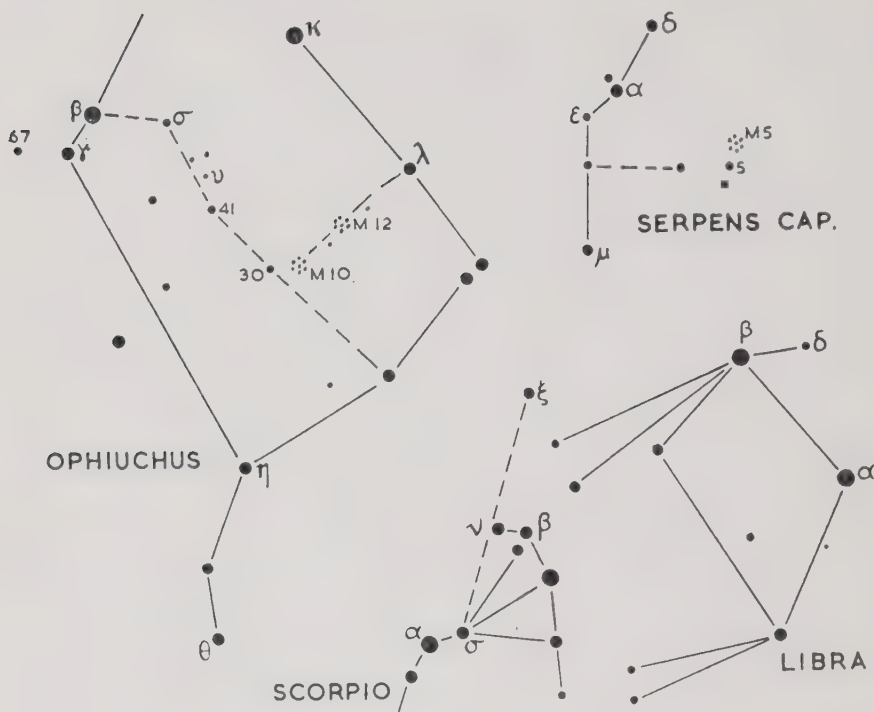
Near α is the globular cluster M 53, which is just visible to the naked eye, and there is a great number of spiral nebulae in the vicinity of 15. M 100, near 24 on the line joining it with σ Virginis, is one of the brightest of spiral nebulae in the Retreat of the Howling Dogs.

Following γ Ophiuchii is 67, a beautiful double star, mags. 4; $8 D = 55''$. The colours of the two components are yellow and reddish. From β over σ we find a little triangle of stars, the lowest of which, U, is a variable of the Algol Type, mag. 5.7—6.7. $P = 1.68$ days.

South of U we find 41 and 30, and near the latter is M 10, a fine globular cluster, and on the line from this to λ there is another globular cluster, M 12.

δ , in the Head of the Serpent, is a difficult double star, mags. 4.2; $5.2 D = 4''$, and this is a binary; the two stars revolve around their common centre of gravity. Below α and preceding it is a triangle, in which 5, a mag. 5 star, guides us to M 5, a fine globular cluster. Its diameter is nearly half that of the Full Moon, and its compact centre is well seen in field-glasses, although it needs a fairly large instrument to show individual stars, the brightest of which are of mag. 11.

South of Serpens Caput is the inconspicuous zodiacal constellation Libra, in which α is a double star which the naked eye can separate under favourable conditions, mags. 2.9; $5.3 D = 230''$. β , although, strictly speaking, not a telescopic object, is remarkable for another reason. It is the only naked eye star which is definitely green; all other stars of this colour are either very faint, or they are the companions in a system of a double star.



Map 17. Snakebearer, Snake, Scales and Scorpion

δ Librae, which can be found easily from β , is an Algol-type variable, mag. $4.8-6.2$, $P = 2.33$ days.

Following Libra are the bright stars of the next zodiacal constellation, Scorpio. Here, β is a fairly easy double star, mags. $2; 5$ $D = 14''$. Next to this is another double, ν , mags. $4; 7$ $D = 41''$, and a line from σ over ν leads us to ξ , rather a difficult double, mags. $4.5; 7$ $D = 7''$.

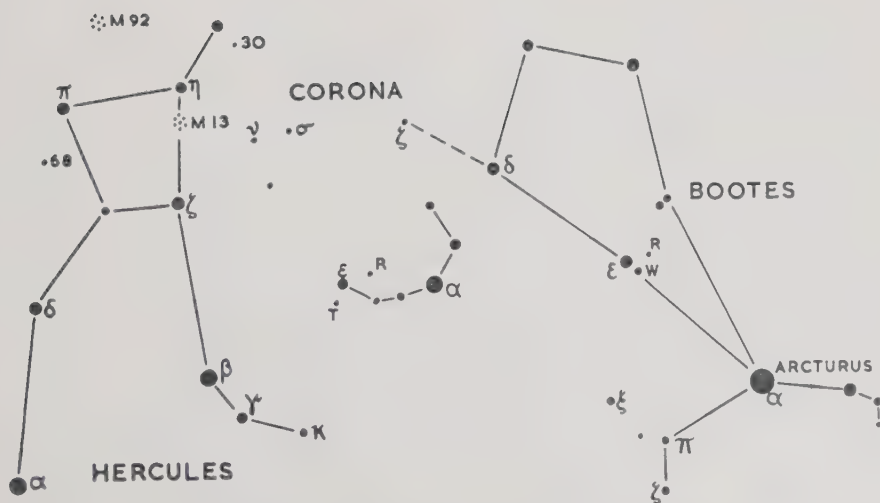
North of Ophiuchus is the large but inconspicuous constellation Hercules, in which α is a variable star of the μ Cephei type. Its magnitude changes from 3.1 to 3.9 , and there is a slight indication of a period of 90 days. Above this is δ , rather a difficult double, the colours of the $D = 10''$.

components being greenish and bluish respectively, mags. $3.2; 8.3$

Towards the left of the quadrangle in this constellation is 68, a variable of the β Lyrae type, mag. $4.8-5.4$, $P = 2.05$ days.

At a distance of about one-third along the line from η to ζ we find M 13, the finest globular cluster in the northern heavens. It is just visible to the naked eye, and presents a glorious view in a telescope. (See Plate XVII.) There are about 30,000 stars in this cluster, and its distance from us is 33,000 L.Y. Not quite as spectacular is M 92, another globular cluster, north of the quadrangle, and this is also just visible to the naked eye. Preceding η and to the north of it is 30, an irregular variable, mag. 4.7—6, and in the Western Leg of Hercules we find two more double stars: γ , which needs a clear sky to see it plainly, mags. 3.2; 8.5 $D = 40''$, and, a little easier, κ , mags. 5; 6 $D = 30''$.

Preceding M 13 is a triangle of stars in which ν is a very wide double, mags. 4.8; 5 $D = 370''$. The fainter of the two is distinctly yellow. σ is also double, the two stars forming a binary system, mags. 5; 6 $D = 6''$. Both these stars belong to the constellation Corona, the main stars of which are a little farther south. Near the eastern end of this is the star T, and we are very lucky if we are able to see this. Usually it is of mag. 9.5, but on rare occasions it flares up, and may reach mag. 2. It is not really a variable star, being more of



Map 18. Hercules, Crown and Herdsmen

the nature of a nova, but the nova-like outbursts are repeated occasionally.

Just inside the Crown is R Coronae, another mysterious star. Usually it is of magnitude 5.5, and stays like this sometimes for as long as two years. But suddenly it fades to mag. 12 or even lower within a few weeks, and after some time increases in brightness until it has reached its former brilliance. No explanation can be given for such behaviour, and many more data, usually supplied by amateurs, must be collected before it is possible to form a theory about the cause of these fluctuations.

The stars ϵ and δ Bootis indicate the position of ζ Coronae, a fairly difficult double star, mags. 4.8; 5 $D = 6''$.

δ Bootis is a wide double, mags. 3.2; 7.5 $D = 105''$, and π and ξ , are rather close, perhaps just a little too close for our instrument to separate them clearly. π , mags. 5; 6 $D = 6''$, ξ mags. 4.8; 6.8 $D = 5''$. Near ϵ are two variable stars, R being a long-period variable, mag. 6—13, $P = 222$ days, and W is an irregular variable, mag. 5.2—6.1.

On one side of α Cygni we find σ_2 , which is a triple star, mags. 4; 5; 6.5 $D = 337''$ and $107''$. The brightest and the faintest of these are bluish, and the third star is yellow. Continuing along this line, we come to 16, a beautiful pair consisting of two mag. 5 stars, $38''$ apart.

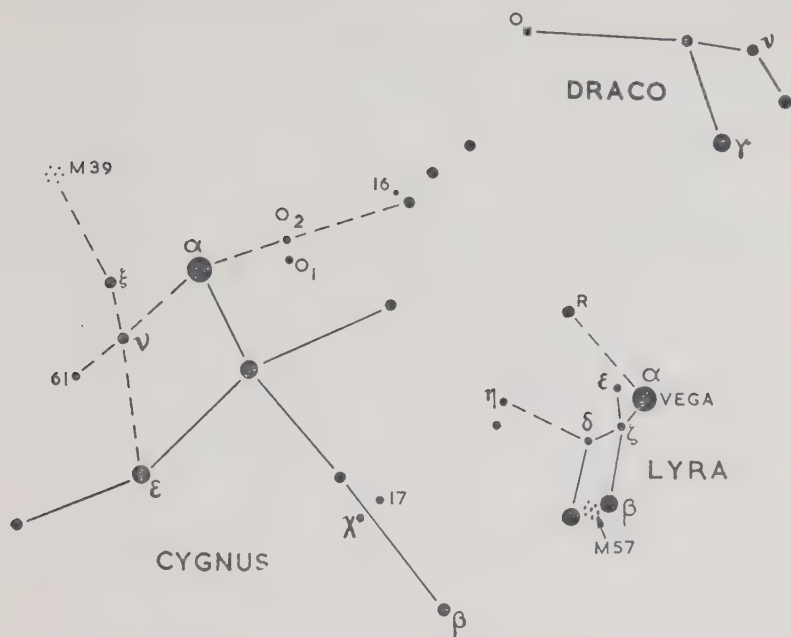
On the other side of α Cygni is 61, the first star whose distance from us was actually measured, and this is also a double, mags. 5.4; 6.1 $D = 23''$. The line from ϵ over ν and ξ roughly indicates the position of M 39, a large open cluster of fairly bright stars.

Near the end of the line from α to β there is an interesting star on each side. χ is a Mira-type variable, which is of mag. 4 at maximum, and therefore plainly visible to the naked eye. At minimum, however, its magnitude is only 13.5, and it is invisible in all but very large instruments. Its period is about 409 days.

17, on the other side of the line, is a double, though rather difficult, mags. 5.4; 8.1 $D = 26''$. β is one of the most beautiful double stars, and it is quite easy to separate even with binoculars. A yellow star of mag. 3.2 has a companion of mag. 5.7 at a distance of $34''$. The colour of the fainter one is a lucid blue.

Near the Head of the Dragon, north-west of the Swan, we find another double star, which is easily separated. This is σ Draconis, mags. 4.7; 7.5 $D = 32''$.

The star ϵ Lyrae is a naked eye double, but on not so clear nights the slightest optical aid will separate the two components, mags.



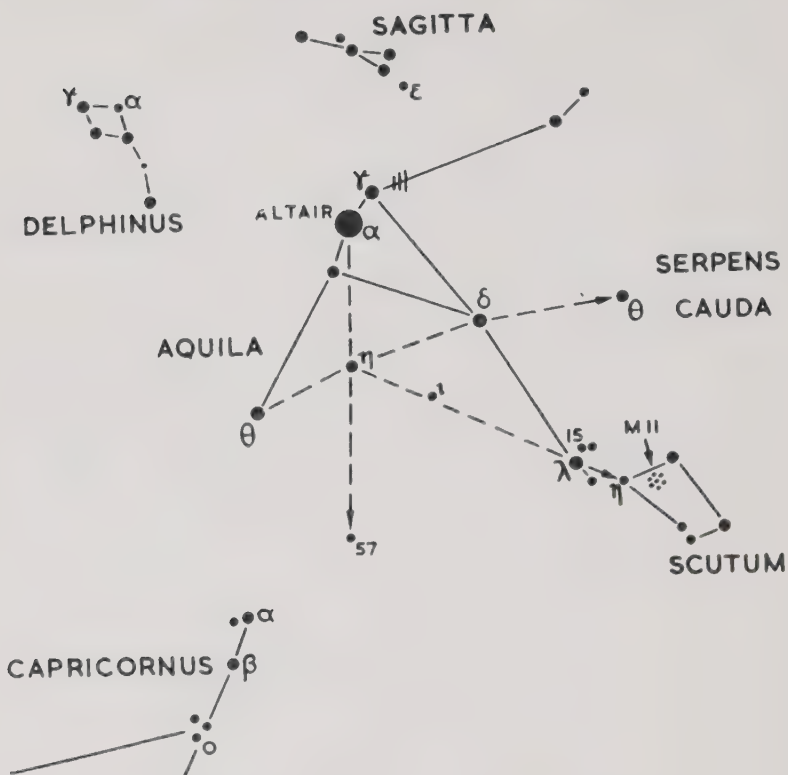
Map 19. The Swan, Dragon and Lyre

4; 5 $D = 208''$. A 2-inch telescope will reveal, however, that each of these stars is double again, and the four present a beautiful picture, as it is possible to have them all in the field of view at the same time.

ζ , also following Vega, but below it, is also double, mags. 3.4; 6 $D = 44''$. The brighter of the two is of a reddish colour, and the fainter is blue-green. Following at a slightly greater distance is δ , which is a naked eye double, consisting of an orange and a white star, mags. 4.5; 5.5 $D = 750''$, and η consists of two stars of mags. 4 and 8, $D = 28''$. It is not always possible to see it as a double, especially when the air is not perfectly clear.

Below Vega, and slightly following, is β , which is the prototype of the bright eclipsing variables. Its magnitude varies between 3.4 and 4.1, and its period is 12.9 days. It is also a double star, having a mag. 6.7 companion, at $47''$ distance. The primary of this double is yellow, and the fainter star is greenish.

At an equal distance from α , but above it, we find the irregular



Map 20. Eagle, Arrow, Dolphin, Shield and Goat

variable R Lyrae, mag. 4—4·7, and half-way along the line joining β with the star following it our telescope will show the ring nebula M 57. The star which is at the centre of this nebula, however, is of mag. 15, and can be seen in telescopes of 12 inches aperture or more only.

Half-way between β Cygni and α Aquilae lies the little asterism of Sagitta, in which ϵ is a fairly easy double star, mags. 5·5; 7·5 $D = 93''$. Following this is another miniature constellation, Delphinus, and here γ is a really beautiful double. The components are of mags. 4 and 5, distance 10'', and the fainter of the two is emerald green, while the primary is yellow. α is also double, but very difficult owing to the faintness of the Comes. Only on one of these one-in-a-thousand nights will our home-made telescope show this as a double. Mags. 4·5; 9 $D = 35''$.

A very striking example of dark nebulae can be seen near γ Aquilae, where one of these 'coal sacks' closely precedes the star. Directly south of α is the Cepheid variable η , mag. $3\cdot7$ — $4\cdot5$ $P = 7\cdot2$ days, and if we continue along this line we come to 57, another double, mags. $5; 6$ $D = 36''$.

Closely north of λ is the 6th mag. star 15, and this is an easy double, mags. $6; 7\cdot5$ $D = 35''$.

A line from η over λ brings us to M 11 in Scutum, a fan-shaped cluster with a bright star at its apex. Binoculars suffice to resolve this cluster into individual stars, and there are dark nebulae below.

α Capricorni is another naked eye double; two stars of mags. $3\cdot2$ and $4\cdot2$ are separated by $375''$. α_1 , the brighter of the two, is double again, having a 9th mag. Comes at $45''$ distance. α_2 , however, which is also double, can be resolved by a 6-inch telescope only.

On clear nights, it might be possible to see β as a naked eye double as well, otherwise opera-glasses will show it so, mags. $3\cdot2; 6$ $D = 205''$. The colours of the two are orange and blue, and in the little triangle below $\circ$ is an easy double mags. $5\cdot6; 7$ $D = 22''$.

For Further Study

WE HAVE come to the end now the reader must decide for himself which aspects of astronomy interest him most, and the following list will give some guidance for further reading.

A useful little book, although very elementary, is *Starting Astronomy* by E. O. Tancock, published by George Philip & Son, 1951. Rather more substantial, and going more deeply into the subject, is *Introducing the Universe*, by J. C. Hickey (Eyre & Spottiswoode, 1952). *Introducing Astronomy*, by J. B. Sidgwick (Faber & Faber, 1951), provides the reader with star maps of each constellation and gives good lists of objects of interest to observers who use nothing more than binoculars, and it also gives notes on the history and mythology of each constellation.

Stories connected with the stars are told by Peter Lum in his *Stars in Our Heaven* (Thames & Hudson), and an extremely interesting book about the different problems of astronomy, and how they were solved, is W. M. Smart's *Some Famous Stars* (Longmans, Green & Co., 1950).

The standard work on the astrolabe is still, after nearly 500 years, Geoffrey Chaucer's *Treatise on the Astrolabe*, which he wrote for his ten-year-old son Lewis, and this clearly shows the astonishing versatility of the instrument.

Many of the problems which we have solved by graphic methods are treated from the mathematical side in *Spherical Astronomy*, by W. M. Smart (Cambridge Univ. Press, 1949), and also in *Elements of Mathematical Astronomy*, by M. Davidson (Hutchinson).

An extremely comprehensive book is *General Astronomy*, by Sir Harold Spencer Jones, formerly Astronomer Royal (Edward Arnold, 1922, reprinted several times), and of a highly technical nature is *The Amateur Astronomer's Handbook*, by J. B. Sidgwick (Faber & Faber, 1955).

Of immense value to the observer is, of course, *Norton's Star Atlas and Telescopic Handbook* (Gall & Inglis, 12th edn., 1954). The surface features of the Moon are described in *Our Moon*, by H. P. Wilkins, (F. Muller, 1954), and *Guide to the Moon*, by Patrick Moore (Eyre & Spottiswoode, 1953).

Finally, there is G. Abetti's *History of Astronomy* (Sidgwick & Jackson, 1954), which describes the development of astronomy from the earliest times, and also tells much of the lives of astronomers and of the instruments they used.

SUN AND SIDEREAL TIME
AT NOON FOR THE
MERIDIAN OF GREENWICH

DAY		DECLINATION	EQUATION OF TIME	SIDEREAL TIME	
		<i>degrees</i>	<i>minutes</i>	<i>hrs.</i>	<i>mins.</i>
Jan.	1	minus 23·1	minus 3·4	18	42·5
	5	" 22·7	" 5·2	18	58·2
	9	" 22·2	" 7·0	19	14·0
	13	" 21·6	" 8·6	19	29·8
	17	" 20·8	" 10·0	19	45·5
	21	" 20·0	" 11·2	20	01·3
	25	" 19·1	" 12·3	20	17·1
	29	" 18·1	" 13·1	20	32·9
Feb.	2	" 17·0	" 13·7	20	48·6
	6	" 15·8	" 14·1	21	04·4
	10	" 14·5	" 14·3	21	20·2
	14	" 13·2	" 14·3	21	35·9
	18	" 11·8	" 14·1	21	51·7
	22	" 10·4	" 13·7	22	07·5
	26	" 8·9	" 13·1	22	23·2
Mar.	2	" 7·4	" 12·2	22	39·0
	6	" 5·9	" 11·5	22	54·8
	10	" 4·3	" 10·5	23	10·6
	14	" 2·7	" 9·5	23	26·3
	18	" 1·2	" 8·3	23	42·1
	22	plus 0·4	" 7·1	23	57·9
	26	" 2·0	" 5·9	0	13·6
	30	" 3·6	" 4·7	0	29·4
Apr.	3	" 5·1	" 3·5	0	45·2
	7	" 6·6	" 2·4	1	00·9
	11	" 8·1	" 1·2	1	16·7
	15	" 9·6	" 0·2	1	32·5
	19	" 11·0	plus 0·7	1	48·3
	23	" 12·4	" 1·6	2	04·0
	27	" 13·7	" 2·3	2	19·8

DAY		DECLINATION	EQUATION OF TIME	SIDEREAL TIME	
		<i>degrees</i>	<i>minutes</i>	<i>hrs.</i>	<i>mins.</i>
May.	1	plus 14·9	plus 2·9	2	35·6
	5	„ 16·1	„ 3·3	2	51·3
	9	„ 17·2	„ 3·6	3	07·1
	13	„ 18·3	„ 3·7	3	22·9
	17	„ 19·2	„ 3·7	3	38·7
	21	„ 20·1	„ 3·6	3	54·4
	25	„ 20·9	„ 3·2	4	10·2
	29	„ 21·5	„ 2·8	4	26·0
June	2	„ 22·1	„ 2·2	4	41·7
	6	„ 22·6	„ 1·6	4	57·5
	10	„ 23·0	„ 0·8	5	13·3
	14	„ 23·2	„ 0·0	5	29·0
	18	„ 23·4	minus 0·8	5	44·8
	22	„ 23·5	„ 1·7	6	00·6
	26	„ 23·4	„ 2·6	6	16·4
	30	„ 23·2	„ 3·4	6	32·1
July.	4	„ 22·9	„ 4·2	6	47·9
	8	„ 22·5	„ 4·8	7	03·7
	12	„ 22·1	„ 5·4	7	19·4
	16	„ 21·5	„ 5·9	7	35·2
	20	„ 20·8	„ 6·2	7	51·0
	24	„ 20·0	„ 6·4	8	06·7
	28	„ 19·1	„ 6·4	8	22·5
Aug.	1	„ 18·2	„ 6·3	8	38·3
	5	„ 17·1	„ 6·0	8	54·1
	9	„ 16·0	„ 5·5	9	09·8
	13	„ 14·8	„ 4·9	9	25·6
	17	„ 13·6	„ 4·1	9	41·4
	21	„ 12·3	„ 3·2	9	57·1
	25	„ 10·9	„ 2·2	10	12·9
	29	„ 9·6	„ 1·1	10	28·7
Sep.	2	plus 8·1	plus 0·1	10	44·5
	6	„ 6·6	„ 1·5	11	00·2
	10	„ 5·1	„ 2·8	11	16·0
	14	„ 3·6	„ 4·2	11	31·8
	18	„ 2·1	„ 5·6	11	47·5
	22	„ 0·5	„ 7·0	12	03·3
	26	minus 1·1	„ 8·4	12	19·1
	30	„ 2·6	„ 9·8	12	34·8

DAY		DECLINATION	EQUATION OF TIME	SIDEREAL TIME	
		<i>degrees</i>	<i>minutes</i>	<i>hrs.</i>	<i>mins.</i>
Oct.	4	minus 4·2	plus 11·1	12	50·6
	8	„ 5·7	„ 12·3	13	06·4
	12	„ 7·2	„ 13·3	13	22·2
	16	„ 8·7	„ 14·3	13	37·9
	20	„ 10·2	„ 15·1	13	53·7
	24	„ 11·6	„ 15·7	14	09·5
	28	„ 13·0	„ 16·1	14	25·2
Nov.	1	„ 14·3	„ 16·4	14	41·0
	5	„ 15·5	„ 16·4	14	56·8
	9	„ 16·7	„ 16·2	15	12·5
	13	„ 17·8	„ 15·8	15	28·3
	17	„ 18·9	„ 15·1	15	44·1
	21	„ 19·8	„ 14·2	15	59·9
	25	„ 20·7	„ 13·2	16	15·6
	29	„ 21·4	„ 11·9	16	31·4
Dec.	3	„ 22·0	„ 10·4	16	47·2
	7	„ 22·6	„ 8·8	17	02·9
	11	„ 23·0	„ 7·0	17	18·7
	15	„ 23·3	„ 5·1	17	34·5
	19	„ 23·4	„ 3·2	17	50·3
	23	„ 23·5	„ 1·2	18	06·1
	27	„ 23·4	minus 0·8	18	21·8
	31	„ 23·2	„ 2·8	18	37·6

CORRECTIONS:

IN LEAP YEARS: January and February:

*Subtract 2 minutes from
Sidereal Time*

March to December:

*Add 2 minutes to
Sidereal Time*

1ST YEAR AFTER LEAP YEAR:

*Add 1 minute to
Sidereal Time*

2ND YEAR AFTER LEAP YEAR:

Use values as tabulated

3RD YEAR AFTER LEAP YEAR:

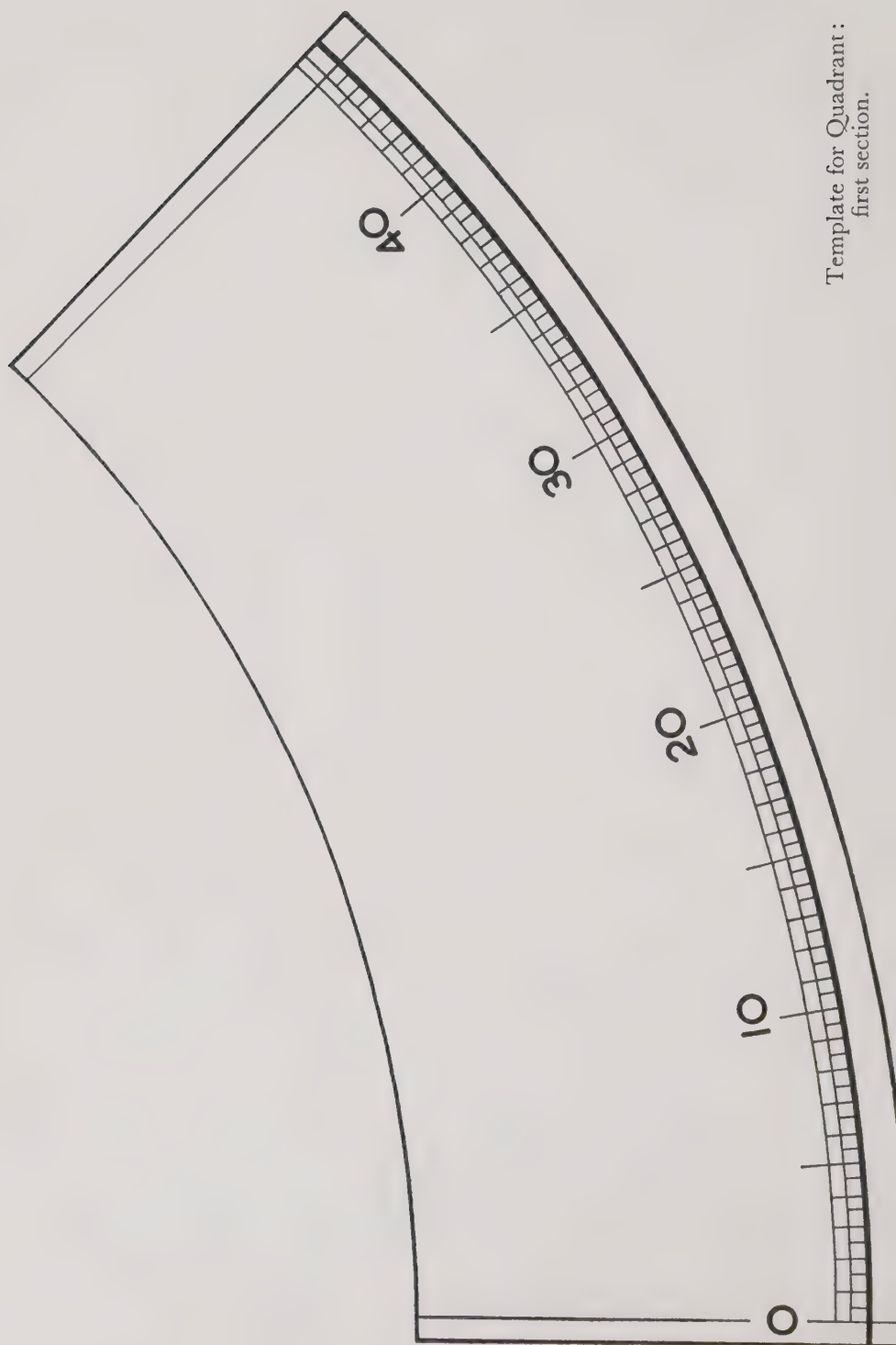
*Subtract 1 minute from
Sidereal Time*

DECLINATION AND EQUATION OF TIME ARE CORRECT AT:

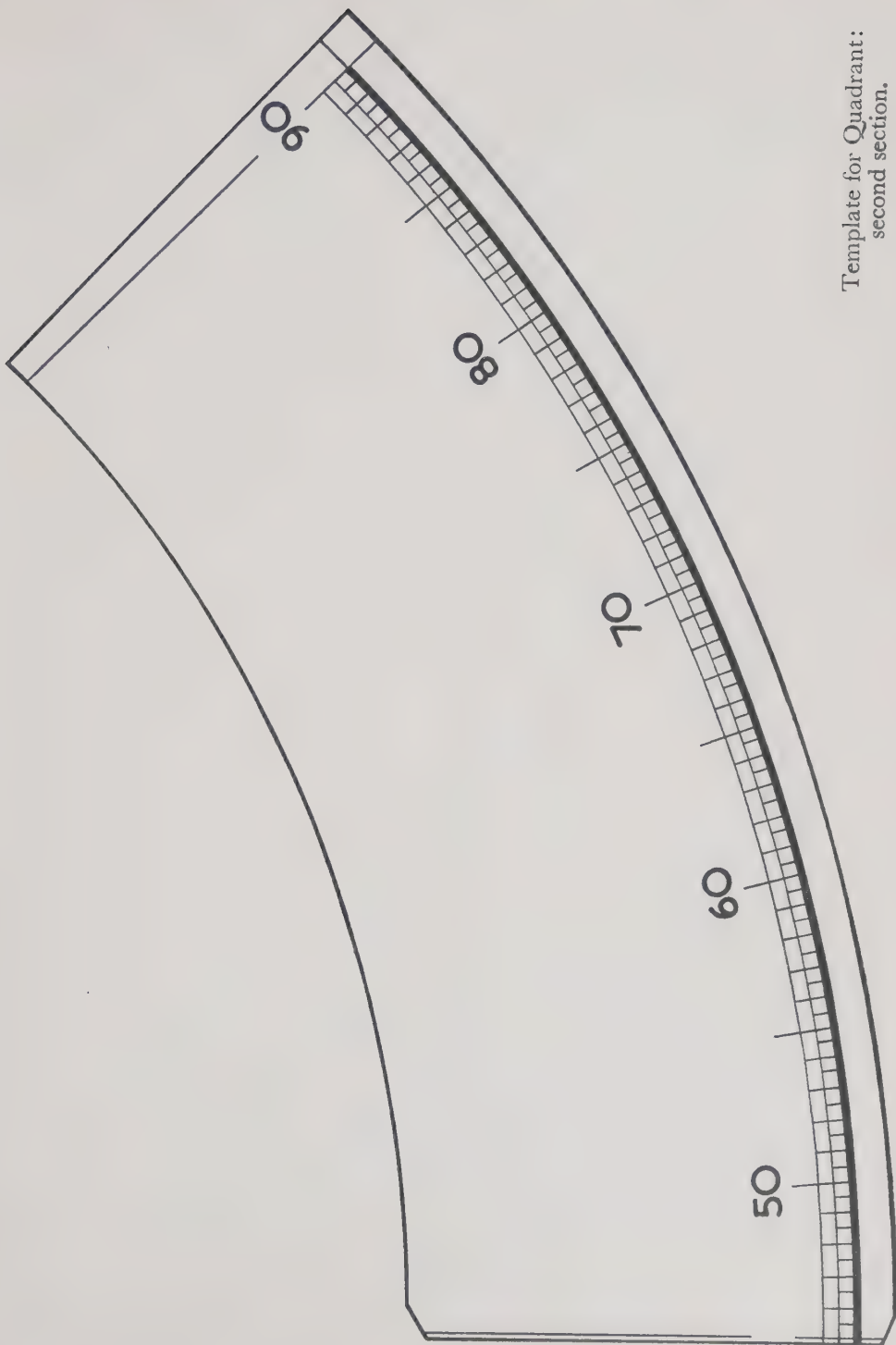
24 hrs. G.M.T. in Jan. and Feb. of leap years,
 00 hrs. G.M.T. from Mar. to Dec. of leap years,
 06 hrs. G.M.T. during 1st year after leap year,
 12 hrs. G.M.T. during 2nd year after leap year,
 18 hrs. G.M.T. during 3rd year after leap year.

INTERMEDIATE DATES:

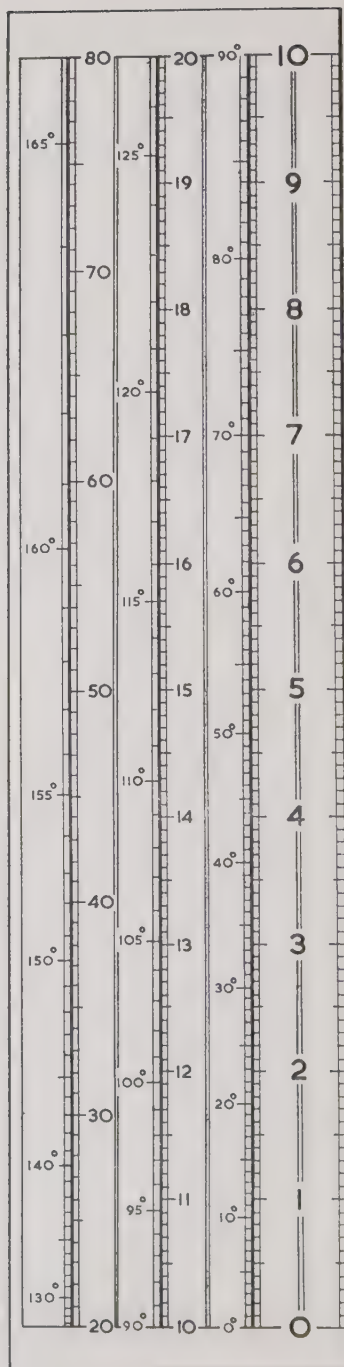
Add 3.9 minutes to Sidereal Time for each day, and interpolate values of Declination and Equation of Time.



Template for Quadrant :
first section.

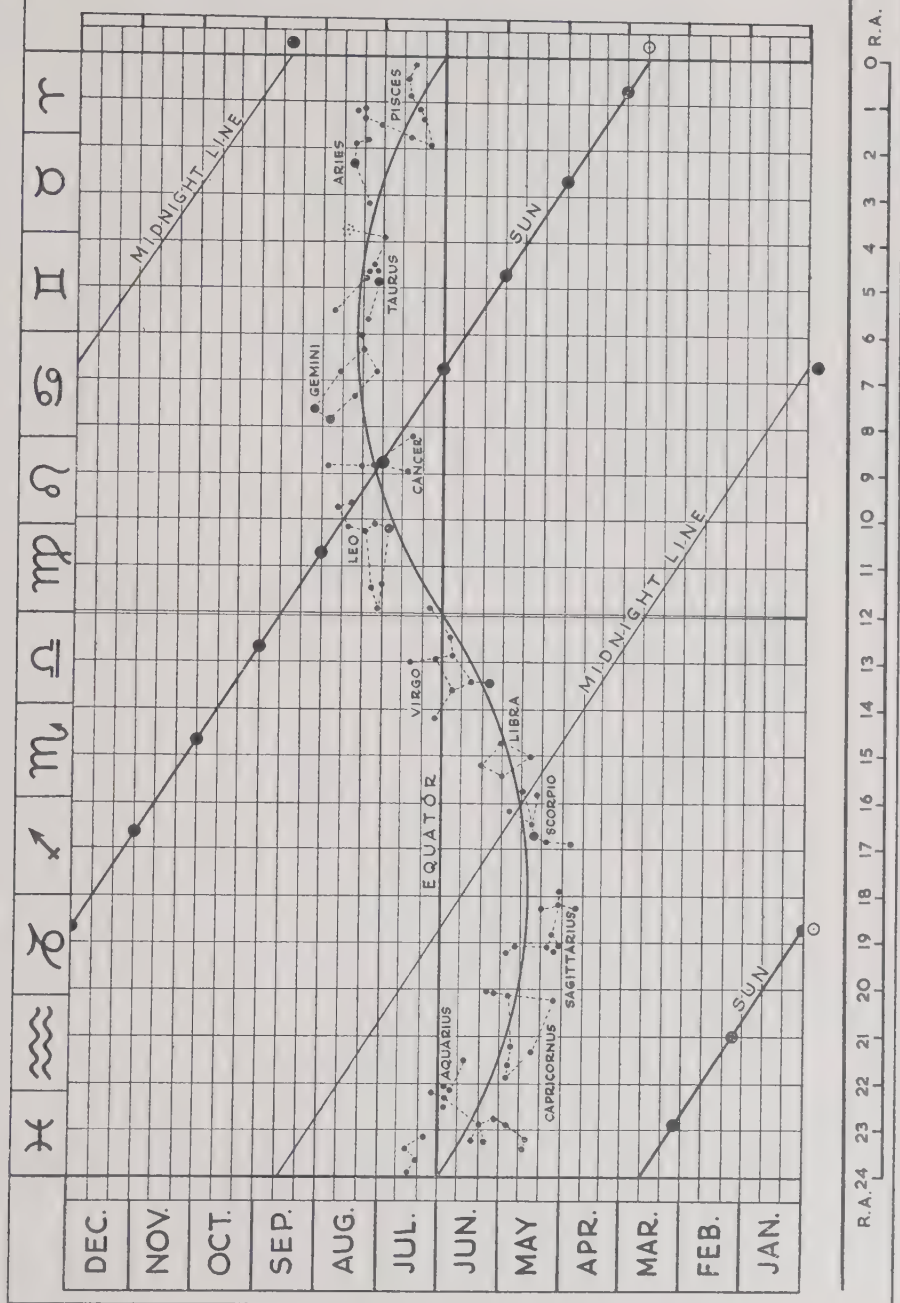


Template for Quadrant:
second section.



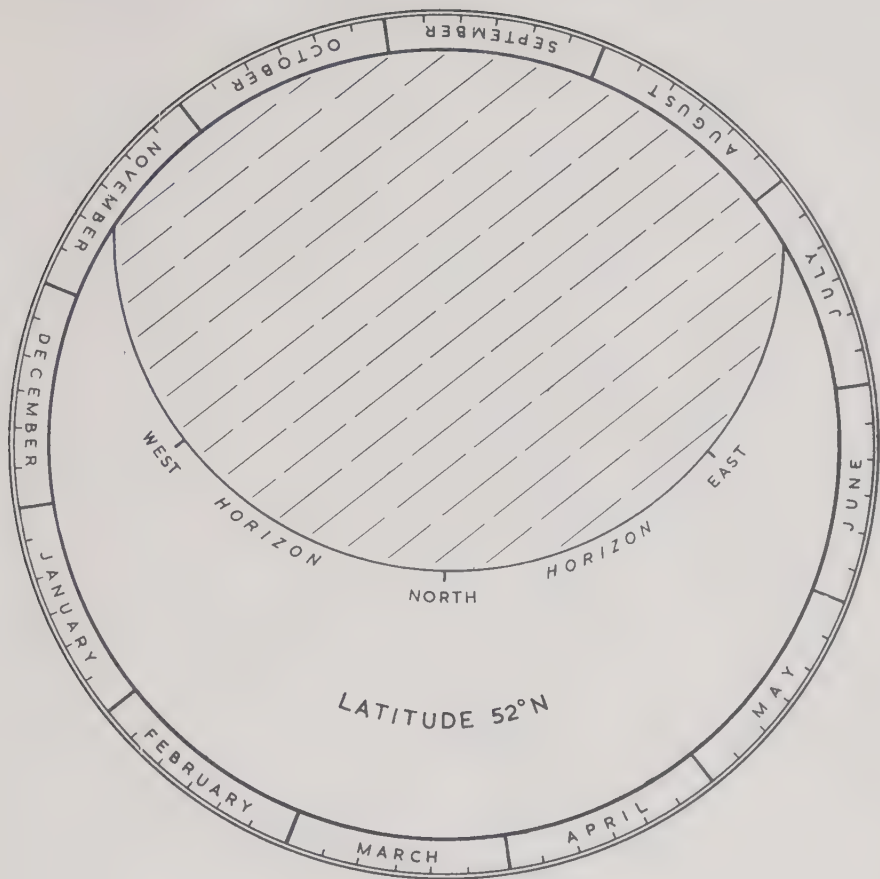
Stereographic Scales

ASTRONOMICAL CALENDAR





Star Map



Mask for the Star Map

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